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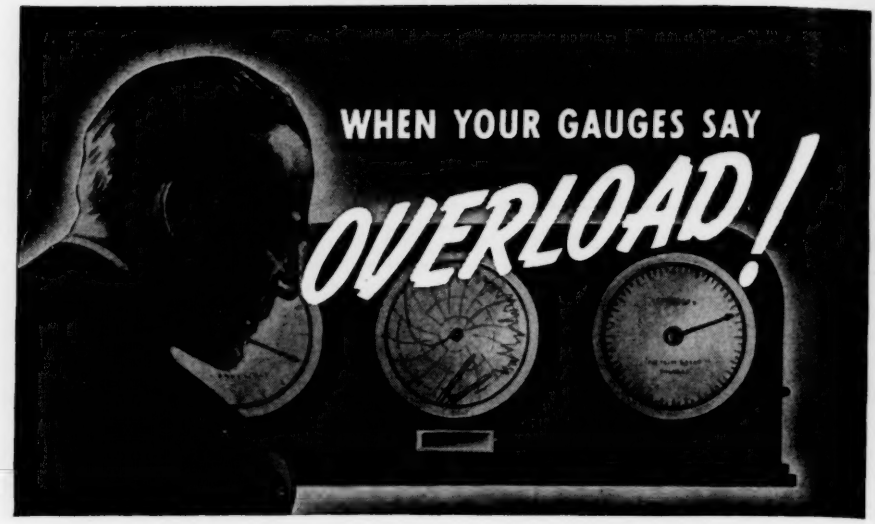

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Water Supply in Wartime

By Robert L. McNamee

THE public water supplies of the United States now serve about 85 million people, nearly two-thirds of the nation's total population. Water supplies subjected to treatment of some kind or other serve some 75 million persons, well over half the population. In breadth of service, the public water supply industry ranks high among public services, providing direct service to more people than any other type of utility, with the possible exception of the electric utilities.

Considered as a basic raw material, the production of water exceeds that of any other commodity. It amounts to about 12½ billion tons per year. Assuming that only 40 per cent of this amount is used as an industrial raw material, the production of industrial water still ranks far above that of all other basic raw materials in the United States. Data for the year 1940 are shown in Fig. 1.

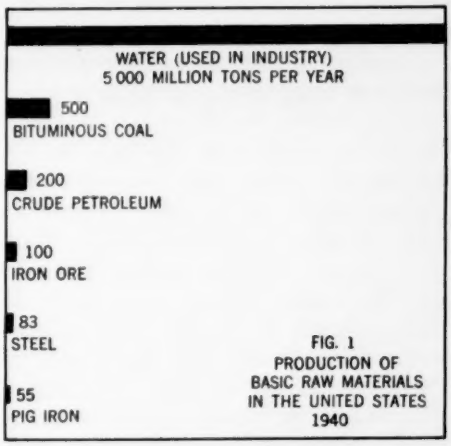

FIG. 1 PRODUCTION OF BASIC RAW MATERIALS IN THE UNITED STATES 1940

The expenditures for water works construction in the United States average over 100 million dollars per year. The material investment in the nation's water supply systems is enormous. It is estimated at about 27 billion tons of material, or about 300 tons of material per thousand persons served. Recent studies have estimated the quantities of materials for maintenance to amount to over 400,000 tons per year or about 5 tons per thousand persons served. Water supply is unquestionably "big business."

A paper presented on April 20, 1943, at the Michigan Section Meeting, Ann Arbor, Mich., by Robert L. McNamee, Cons. Engr., Shoecraft, Drury & McNamee, Ann Arbor, Mich.

Water Supply and the Civilian Population

Water supply service is so commonplace that its importance to a civilian community is not realized by many people. Only at a time of disaster, such as flood, conflagration, internal strife or war, does its absolute value become generally apparent. The failure of a pumping plant or the bursting of an important main leaves an affected area without fire protection and subject to water-borne disease. Thus it becomes a catastrophe to the people who must bear it. Such hazards as these are multiplied in time of war, because of the altogether abnormal conditions surrounding civilian living conditions in such times.

Probably about 10 million persons are now employed directly in war work, and by the close of 1943 that figure is expected to increase to 20 million or more. A year ago, the migration of war workers from one part of the country to another involved over 3 million persons; by now that figure has probably been doubled. The bulk of young and middle-aged manpower is already distributed among the armed forces, industry and agriculture. Women are now contributing in large measure to war industry and their numbers in this field of service will increase.

Despite the repeated pleadings of federal agencies against mass migrations into areas of war industry, such migrations have continued to take place. The consequent concentration of populations has inevitably produced crowded housing and temporary housing.

The public health aspects of these conditions are serious. The stress of living within this environment results, among people of certain backgrounds, in a breakdown of never well established habits of personal and community hygiene. The opportunity then exists for the spread of water-borne diseases.

Where these shifting populations can be absorbed within established municipalities, their water can usually be provided by the existing public supply, though often this involves expansion under some difficulty. The settlement of populations in areas not already served with water supplies creates a much more hazardous condition. In suburban and rural areas, well supplies of undetermined quality are developed and used, at times in close proximity to inadequate subsurface sewage disposal.

Water Supply and Industrial Production

Water is an important industrial raw material—as important as steel, oil or lumber. In a consideration of the location of key industries, the available supply and quality of water are now carefully investigated.

The use of water for sanitary purposes is common to all industries. There must also be an adequate supply of safe and palatable drinking water. All water so used, of course, in the end becomes the vehicle of sewage disposal, which makes possible the concentration of many employees in close quarters and conserves space, without inducing serious public health problems.

Within recent years, the uses of water as a part of industrial processes have greatly increased. Important among these uses are boiler feed water; water actually incorporated in the product; water as a vehicle for handling material, for product cooling, for product cleansing and for indus-

trial waste disposal. Most plants producing their own prime power use considerable quantities of water for boiler feed. In this use, quality is a most important consideration.

Typical of many industrial chemical processes in which water is involved is the manufacture of industrial alcohol. About two gallons of water are used in the digestion of grain to produce one quart of alcohol. In addition, large quantities are employed as a cooling agent in the distillation process.

Certain types of industries employ water as a means of handling material. An example of this use is the paper industry, in which the paper stock is reduced to suitable form and conveyed to the paper machine in a water suspension. Much of this water is later extracted and reclaimed for re-use in the process.

Water of suitable temperatures is an excellent cooling medium and is so used in many industrial processes, both for direct cooling, as in condenser work, and for indirect cooling, as in air-conditioning of process rooms, test rooms and the like.

A great many processes involving chemical treatment of products use water as a cleansing agent after the treatment process. This is well illustrated in the pickling of steel and in the cleansing of food products and of textiles.

Much water is employed as a means of industrial waste disposal, particularly for the dilution and neutralization of spent acids and alkalis.

The quantities of water required for these various industrial purposes are large. Some steel mills use 10,000 to 15,000 gal. per ton of ingots produced. Airplane motor plants using water for cooling purposes may require as much as 50,000 gal. per plane motor; paper mill uses range from 25,000 to 100,000 gal. per ton of paper produced. There is no common denominator for relating water requirements to industrial production.

The many and great changes in industrial methods that have been brought about in wartime affect the demands of industry for water. Existing plants have been converted to war production; extensive enlargements have been made to many plants and in practically all plants engaged in the manufacture of war weapons, there has been a marked speeding up of production. These changes have resulted in higher production rates from each plant, machine or unit and have required three-shift 24-hour operation in many cases.

The difficulties in securing mechanical cooling equipment have required the development of water cooling under certain conditions.

All of these changes in production methods have tended to increase the demand for water, in some cases to the point of its becoming a serious burden upon the water plant. Local industrial ground-water supplies developed for particular plant uses have been exhausted, with the consequent imposition of additional loads upon public water supply systems.

Under present conditions of stress, each demand for an increase of water supply should be carefully scrutinized to discover means by which the needs may be held at the lowest practicable minimum. The use of mechanical cooling instead of water cooling, the clarification and reclaiming of used water and the successive uses of water in several processes should all be investigated and employed wherever practicable.

Water Supply for the Armed Forces in Civilian Communities

Of the more than a thousand training centers in the continental United States, about a third have utilized nearby public water supplies for water service. The uses of water in these establishments are not unlike those in normal civilian residential communities. Adequate and safe water supplies must be provided for drinking purposes, for normal cleansing purposes in wash rooms, laundries and the like and as a vehicle for sewage disposal. In some types of establishments there are additional requirements, such as those for the washing down of motor vehicles, airplanes and other equipment.

Where the existing local public supply is able to meet the demands of nearby military establishments, its use for the necessary supply is usually the best solution. As a general average year-round rate, the demand of such establishments is about 70 gpd. per capita.

Water Supply for Fire Defense

From earliest times, water has been the most essential implement of defense against large and stubborn fires. It remains, even now, as the last line of defense after more specialized means have been exhausted.

The normal demands upon a public water supply for fire defense purposes are adequately met by provision in accordance with the standard table of required fire flow of the National Board of Fire Underwriters. Wartime demands for water for fire defense, however, must be modified because of changed conditions. Fire has now become a war weapon against civilians. The incendiary bomb, a comparatively light missile, weighing usually about two pounds, is most effective when widely spread over densely built-up areas. This means of attack, using the weapon of fire, has been extensively employed in the present war.

The official British Government booklet *Front Line 1940–41* has released some information concerning the blitz on London. The opening stroke of the blitz on September 7, 1940, left 9 conflagrations, 19 thirty-pump fires, 40 ten-pump fires and a thousand smaller fires, most of which would have been front-page stories in peacetime. The fire blitz has been felt in every country that has borne an air attack.

Crowded housing induced by the migration of industrial workers seriously increases the normal fire hazards. The fitting up and use of attic rooms, hallways and other commonly unoccupied areas enlarges the fire hazard in existing structures. The construction of temporary housing, equipped with inadequate and makeshift heating and electrical equipment, creates a most serious fire hazard.

Much appurtenant and temporary building construction in wartime is done without adequate inspection and approval. Shortages of materials make it difficult to secure approved equipment. All these conditions tend toward a greater congestion and increase the normal hazards of fire. A large part of the production of wartime materials involves the making of munitions, which in its very nature presents a great fire hazard. In many other war industries, the processes involved are equally hazardous.

British data indicate water requirements for fire defense to be about 5000 to 10,000 gpm. for warehouses, fac-

tories and locks. The New York City Fire Department believes that U.S. buildings present a fire hazard far greater than do the British and even more than do German structures. In addition, the U.S. density of development (about 35 per cent in large cities) is greater than that in England (about 20 per cent).

The burden of protection against fire falls primarily upon water supply facilities. Any plant that may be expected to cope with these conditions should fully meet the requirements for local fire defense situations and, in addition, should provide for auxiliary supplies, standby pumps and local storage at points of unusual hazards.

Military Value of Civil Water Supplies

In addition to meeting the demands of civilian populations, of industrial production and of fire defense on the home front, the public water supply is of utmost importance to our military operations.

This war has exemplified the absolute dependence of military success upon public morale. In the early days of the Nazi conquest of continental Europe, nations fell quickly upon Nazi attack, principally because of a rapid undermining of public morale. Not until the English Channel was reached was there an organization of the home front adequate to cope with attempts at both external attack and internal sabotage.

Water supply stands high among the public services tending to bolster public morale. It is significant that throughout all attacks upon the city, the sources of London's water supply and the means of its transmission to the city have never been put completely out of service. Local areas have been deprived of normal water supplies, but auxiliary equipment has usually been placed in service promptly and water has been delivered. On the other hand, it appears that the loss of water supply was important in the capitulation of both Hong Kong and Singapore. No loss than can befall a congested city is so demoralizing as that of losing its water supply.

High public morale is a direct factor influencing both the quantity and quality of the industrial production of weapons of war. A functioning water supply is fundamental to this morale. The maintenance of high industrial production is similarly directly preserved by an unfailing water supply, adequate to meet the demands within these plants and sufficient in amount to protect them against extensive fire losses.

In this war there have been instances where water supplies have directly supported military operations. This situation has been reported to have existed at Leningrad and Moscow, where the "firing" front was within the range of service of existing public water supplies. The abilities of these supplies to assume the burdens, not only of serving these besieged cities, but in supporting military operations at their gates, have been highly important in holding these Russian fortresses.

At least one instance of the use of water as an offensive combat weapon is known. In one of the several unsuccessful Nazi attacks upon Stalingrad, the Russians suddenly doused a company of German infantrymen with hose streams. In the subzero temperatures, the men and their equipment were frozen stiff on the spot.

Water Supply Situation in Michigan

The United States has been dubbed "The Arsenal of Democracy." If such it is, then Michigan is the production plant of that arsenal, for in that state are produced many of the basic raw materials of war, as well as complete assemblies or subassemblies for substantially every type of war weapon and equipment used by the United Nations. This fact has a very important bearing upon public water supply service in the state.

Population: According to the 1940 census, the southeastern Michigan industrial area had a population of about 3¼ million, more than 60 per cent of the total population of the state. In terms of urban population, the area included nearly 75 per cent of the state's population. In this area, the Detroit region, including eight industrial centers within a 100-mile radius of the city itself, in 1940 had an aggregate population of about 2½ million, which by 1943 had risen to over 3 million.

To some extent this increase was the result of an influx of workers from other states, but in part at least it represented a shift from rural areas and small towns to the cities. There are, of course, situations, such as that at the Willow Run Bomber Plant, where new populations are being settled in rural areas surrounding outlying industries, but these shifts of population inevitably result in congested housing conditions. Not only are practically all usual dwellings occupied—in many cases doubled up—but many structures, such as garages, summer cottages and trailers are occupied as year-round dwellings. In some instances beds are occupied for two or three shifts each 24 hours.

A consequence of shifted populations, crowded living conditions, high wages and the lack of normal recreational opportunities is a general slackening of the usual social controls of normal home life. Public health is directly affected by these conditions. Shifting populations induce a mushroom development of food stores and restaurants, taxing the capacities of local health authorities to supervise them, giving opportunity for food-borne and water-borne disease to become epidemic. Crowded housing fosters the spread of contagious diseases. Lack of rest and recreation lowers the resistance of the human system to attack of disease. Rural and suburban home water supplies and sewage disposal are often improperly installed and supervised.

Fire hazards are always increased by congested housing. The same war impetus that brings about congested housing induces temporary construction work, improvised electrical work and heating systems and inadequate provision for waste and rubbish disposal. Under the stress of wartime conditions, the usual safeguards of building and housing inspections and permits are overworked and therefore often inadequate.

Industry: The industrial development of southeastern Michigan has expanded in even greater degree than its population. The peacetime record production occurred in 1929 and amounted, in terms of civilian motor vehicles, to about 5½ million units. The war production of this area, converted to equivalent terms, will be about 15 million units.

Normal peacetime production has been valued at about 3.5 billion dollars per year. Some estimates place the

1942 war production value at 8.0 billion dollars per year and predict much higher figures for 1943.

For 1940, industrial employment in the Detroit region aggregated 500,000; for 1943, 800,000. The corresponding data for the smaller towns would increase these figures materially. Outstate communities are at work producing raw materials and finished products of war with the same energy and zeal.

Water Supply: In the aggregate, the effects of the increases in population and stepped-up production upon the water supplies of the area are tremendous. The municipal supplies serving the Detroit region were probably delivering a total of about 340 mgd. as an annual average in 1940; now the demand will probably reach 425 mgd. Not only does this demand fall upon the sources of water, but upon treatment, pumping and distribution equipment as well; and at a time when it is most difficult to make extensions to plant.

Mobilization for Defense

All that has been said concerning the magnitude of the public water supply industry and the absolute dependence of civilian, industrial and military operations upon it serves to emphasize the problems that confront the water works managements of American communities.

It is the responsibility of each system manager or superintendent to examine and evaluate his own situation and to prepare to defend it effectively against any eventuality. He alone can assure that, if and when it is ever put to the test that so many foreign cities have undergone, it will not be found wanting.

EDITORIAL NOTE: For the local system evaluation mentioned above, the author distributed a self-audit questionnaire to be filled out by the water works executive on his return to his home city. This questionnaire, entitled "Self-Examination of Water Works Preparedness for Wartime Conditions," was published in the May JOURNAL (p. 602) as part of the report of the Michigan Water Works School at which the paper was presented.

Co-operation Between Water and Fire Departments

By Arnold C. Renner

WATER is the best extinguishing agent there is for general fire fighting operations. The principal reasons for its great effectiveness are that it is chemically stable under ordinary fire conditions and that it is one of the best cooling agents available. In addition, water flowing over burning material excludes the oxygen of the air, without which common materials cannot burn.

A city water supply is primarily designed for producing an adequate, palatable and potable water for domestic, commercial, industrial and public service, and, in addition, a reasonable quantity of water for fire protection. Although water for extinguishing fires does not need to be a potable supply, it is apparent that the most efficient method is to supply water for both domestic and fire through the same system of mains. This is the method used except in several of the larger U.S. cities where separate high-pressure fire systems have been installed in addition to the regular water systems.

It can be shown that the smaller the city the more of the physical properties of the water works are required for fire protection. In cities of less than 10,000 population that part of the water system required for fire protection may run from 60 to 80 per cent of the total, whereas in the larger cities this percentage runs from 10 to 20 per cent. In terms of population, the cost of furnishing fire protection will run about $1.25 per capita in the larger cities, and double this amount in the smaller ones.

Fire Protection Charges

The question of charges made by the water department for fire protection is a much discussed subject. In many of the smaller towns the water department charges the fire department from $25 to $75 for each hydrant, but this means little as it is generally only a matter of bookkeeping and actually the consumers of water pay for furnishing fire protection through hydrants.

When a building owner installs automatic sprinkler equipment, the city water supply may be sufficient to furnish the required amount of water at adequate pressure, in which case the water department feels that the owner of this property should reimburse the water department for its readiness to serve him in case of a fire. In some towns this charge is made on flat yearly basis or by charging 5 cents or some such figure per sprinkler head. Many cities make a yearly charge based on

A paper presented on April 22, 1943, at the Michigan Section Meeting, Ann Arbor, Mich., by Arnold C. Renner, State Fire Marshal, East Lansing, Mich.

the size of the connection. This latter method is probably the fairest, providing the charge is not excessive. In Detroit the charge for a service for fire protection varies from $24 a year for a 4-in. connection to $48 a year for an 8-in. connection. Due to the fact that the owner who installs the sprinkler system makes it unnecessary for the city to furnish additional fire protection, this charge should not be excessive but should cover only the cost of maintenance and inspection of the service connection.

Statistics will show that the automatic sprinkler is almost infallible; therefore, in the event of a fire in a sprinklered risk there is, in most cases, very little extinguishing to be done by the fire department.

Sprinkler Connections

Some cities permit unmetered sprinkler connections, while others require meter or detector checks. If a meter is required, it should by all means be a low-loss meter, for the ordinary domestic 6-in. meter will produce an excessive pressure loss; whereas with an approved fire meter, the loss will not exceed 2 or 3 psi. in a 6-in. meter with up to 1000 gpm. flowing. A detector check permits a full flow of water when the check is open, and provides for detecting leaks or the theft of water by the operation of a small bypass meter. This method is considered acceptable in many Michigan cities. A number of automatic sprinkler systems are furnished with water from a nonpotable supply, and the State Board of Health will not permit cross-connections of any kind with the city potable system. On the question of health, the fire protection engineer is not in a position to argue with the sanitary engineer.

Adequacy of Supply

The National Board of Fire Underwriters has worked out a formula on the amount of water which should be available in the downtown area of a city or town. As an example, a town of 1000 population requires a fire flow of 1000 gpm.; 5000 population, 2250 gpm.; 10,000 population, 3000 gpm.; 28,000 population, 5000 gpm., etc. A minimum of 1000 gpm. should be available for fire protection in dwelling districts regardless of the size of the city. It necessarily follows that there are very few small towns where these amounts of water are available in either mercantile or residential sections, but in the larger cities the required amounts are generally available, for the large city must be in a position to supply peak loads which are in excess of the fire protection demands. It should be pointed out that on the average the population of a city is directly proportional to the size and extent of the property to be protected.

From a fire protection standpoint, a good water system should not only be such as to supply the water required for fire protection and domestic consumption, but the system should be in duplicate as much as possible so that its reliability may be increased. The N.B.F.U. Standard Schedule for Grading Cities and Towns (published as a part of the October 1942 JOURNAL) requires that, with the two largest pumping units out of service, there shall be sufficient pumping capacity remaining to supply the required demands. Such a condition is found to exist in the larger cities, but it is impossible, or at least impractical, in the smaller towns. Suction and discharge lines, filter capacity, sources of power, etc., should be duplicated as much as possible.

Elevated storage is not only the most reliable source of supply, but permits a centrifugal pump, which is used in most towns, to operate only at intervals and at its maximum efficiency, whereas in a direct pumping system, pumps of the centrifugal type must operate at all times regardless of the consumption demand. The main feeder of a system should be of sufficient size to furnish maximum domestic consumption plus fire flow to the mercantile section at at least 20 psi. pressure, this figure being used in computing the amount of water available for pumper suction. Minor distributors, even along residential streets, should consist of 6- and 8-in. mains. In many of the smaller cities as much as 30 per cent of the total length of mains are 4-in. It can be readily shown by friction-loss tables that 1000 ft. of 4-in. dead-end main in the average water system will furnish only about one fire stream of 250 gpm. to a pumper. The gridiron should measure as nearly 600 ft. as possible on the long side of the block, and dead ends should be eliminated as much as possible.

A number of years ago in the average small town there existed a so-called Holly water system where the pumping units were driven by steam. It was the practice in those days normally to operate the pumps at from 50–60 psi. pressure. In the event of a fire, the water works attendant actuated a steam whistle for calling the volunteer firemen and boosted his pump pressure to 100 psi. This permitted the fire department to fight the fire with direct hose streams from the hydrant, although in many cases where the distribution system was poor due to small mains and dead ends or where large quantities of water were required, the 100-psi. pressure was insufficient for adequate hose streams; but another result was obtained, namely, after every fire the water department received calls from citizens that service connections and plumbing were leaking. In other words, a constant pressure at the water works regardless of what pressure is carried will show much less trouble than the raising of pressure every time there is a fire. In most cases the raising of pressure was unnecessary as 80 per cent or more of the fires were extinguished by hand or tank chemicals, and it was not necessary to use the water system. With very few exceptions, all Michigan cities having water supplies are provided with pumpers in the fire department so that in general the raising of pressure is not required, providing the distribution system has been designed to furnish an adequate supply at 20 psi. pressure. This in general requires larger mains in the smaller cities although a well-designed distribution system should be able to deliver adequate water for fire protection, and in so doing, domestic consumption is well provided for.

It is important to both the fire and water departments that they know how much water is available for fire protection in different parts of the city, and this information can be obtained only by conducting flow tests throughout the city. Flow tests are not only valuable for determining the amounts available, but for proper control of water system improvements.

Hydrant Control

The making of flow tests and the marking of hydrants uniformly are recommended by all interested organizations. (*See* the A.W.W.A. Specifications for Uniform Marking of Fire Hydrants, reproduced at the end of

this paper. It is to be noted that the N.F.P.A. system of recommended painting varies only slightly in that the color yellow is designated instead of orange for Class B.) Although the flows indicated by the markings would be materially disturbed by change in consumption conditions and the opening of other hydrants in case of a large fire, they may be accepted as relative and furnish a fairly good measure of the capacity of the distribution system. As far as the author knows, only one city in Michigan—Kalamazoo—has conducted such tests.

It is highly important that the fire department have an up-to-date map of the distribution system showing the size of mains and location of gate valves and hydrants so that the firemen may have a relative idea of the weaknesses of the water system. There are a number of small towns in Michigan where the only record of the water department is a print which seems to be the personal property of the water works superintendent. Adequate records of all parts of the water system should be on file at the water office.

Hydrant Maintenance

In Detroit the fire department not only inspects and maintains, but actually installs the hydrants. This method of operation is undoubtedly impractical in the smaller cities, and, as a matter of fact, most cities hold the water department responsible for the installation and maintenance of hydrants. This may be done to the satisfaction of both departments by close co-operation, but sometimes it produces a division of responsibility. There are a number of cases on record where fire departments have reported that certain hydrants were useless at the time of a fire because they were found to be frozen or otherwise inoperative. If the fire department is assigned the duty of inspecting, especially for freezing, and the defects are corrected by the water department, the latter is being held responsible for maintenance, and good results obtain. In any event, the co-operation between the two departments with respect to hydrant care should be well defined. Some fire departments carry valve keys; however, the author believes that the opening or closing of gate valves should in general be left to the water department as its sole responsibility. In some cities there exist both right and left hand valves which may produce a complication. There are a number of cases on record where flow tests have indicated that there was an obstruction in the system and an investigation has shown that a gate has been closed, whereas it was supposed to have been opened. Detailed records should be kept of both hydrant and gate valve inspections so that a condition of this kind can be traced to the responsible person.

When a frozen hydrant is found, it should be restored to service as rapidly as possible. Time is a very important factor for no one can foretell which hydrant will be operated at any given time. There are several ways to thaw a hydrant. Rock salt has been used with good but very slow results. Electricity has been used but it was not suitable, being too slow. Hot water has been used and is still used in some of the smaller towns. Steam has been found the fastest and best means. New York City has several of the steam thawing units in service and has found them the most practical. In deciding on the system of thawing to be used by the fire department or the

water department, the officials must answer these questions: Is it effective and how fast does it operate? Remember, fire will not wait! It will go crackling up the walls while the firemen at the corner are cussing at the hydrant that refuses to be thawed.

Auxiliary Water Supplies

So-called static water supplies are used by most fire departments and must necessarily be utilized in the small town where there is no water system, but as a general proposition the use of a static water supply is not desirable due to the presence of dirt, leaves, debris, etc. It takes very little foreign matter to make a pumper inoperative, or at least it may be slowed down by leaves and trash caught in the strainer. Some of this foreign material goes through the pump and in the case of a rotary pump, and to a lesser degree a centrifugal pump, it is harmful. It is also a fact that a pumper taking supply from a river or cistern may pump into sprinkler equipment which might pollute the city supply. So, as a general rule, the fire department should be required to use the city supply as much as possible for extinguishing fires. It follows, however, that in case of air raids any available water supply should be utilized, and, moreover, it would be farsighted to provide for pumper landings and storage facilities so that the static supplies would be readily available.

As a matter of fact, it can be proved, that, in general, the water distribution systems of the United States are much superior to those of Europe. It is possible in many cities, especially in the larger ones, to supply a considerable amount of water through hydrants even if a 6-in. or smaller main is broken due to bombing.

It is also possible to utilize the water running from the break in some cases for pumper suction. This actually happened at Hickam Field in Hawaii on December 7, when a fire department pumper took suction from the bomb crater which was filled with water from a broken main.

Program for Co-operation

In conclusion, the program for securing closer co-operation between the Westchester, N. Y., fire and water departments is presented and the author personally recommends that all cities and towns work out a plan similar to this, if they do not have one:

1. Adequate maps of the public water supply system showing hydrants, valves, sizes of mains and other pertinent information shall be furnished by the local water works to the fire department. It shall be the duty of the fire department to acquaint its members with the information contained on the maps. In addition, the water superintendent shall furnish the fire chief with other information with respect to the water system that he believes the fire chief and certain of his key men should know but which should otherwise be kept confidential.

2. A study as to pressure and amount of water available for fire protection in all sections of the community served by the public water supply system shall be made by the fire department with the assistance of the water department.

3. Where possible, arrangements should be made to have a representative of the water department answer all first alarms in the principal mercantile districts and all second alarms elsewhere.

4. The fire departments of the county have already adopted a pro-

gram of standardization of hose and hydrant threads with special consideration as to the facilities available in neighboring counties. Each fire department shall check its inventory of adapters to see that it has a sufficient number of all sizes and threads necessary on hand. Water departments should know the sizes and threads used in their neighboring communities so that they will be prepared to obtain water from adjoining communities where feasible by the hydrant to hydrant method.

5. All fire hydrants shall be suitably marked to indicate the volume of water available. The system should be agreed upon between the water department and fire department and shall be either the system of colors approved by specifications such as those given at the end of this paper or should consist of having the size of the street main painted on the fire hydrant; or both systems may be used.

6. Both departments should review jointly the possibilities of inter-community hookups, both main to main and hydrant to hydrant. The fire chief should be acquainted with existing emergency hookups.

7. A joint study should be made of the possibility of obtaining an auxiliary water supply by waterside approaches at points on rivers, streams, ponds, brooks, etc., where fire department pumping apparatus may be located (or sea hydrants installed). Consideration should be given to possible location of small dams or other devices to form pools or suction wells for fire department uses.

8. The fire department shall be advised that no auxiliary supply of water is to be pumped into any water main unless such action has been first approved by the water department and health department.

9. Shut-off keys for operating valves on street mains should not be furnished to the fire department. The operation of valves in a water system requires scientific knowledge of pressures, gates, etc., and the operation of such valves by the fire department might cause serious damage to the water system.

10. A semi-annual routine inspection of all hydrants should be made to see that they operate freely and have suffered no damage.

11. All chains shall be removed from hydrant caps.

Specifications for Uniform Marking of Fire Hydrants

The American Water Works Association, recognizing that the adoption of a capacity marking scheme by any water department is optional, herewith provides the following uniform color scheme for painting hydrants rated in terms of their relative capacity.

1. Hydrants are classified as follows:

Class A: Hydrants that on individual test usually have a flow capacity of 1000 gpm. or greater.

Class B: Hydrants that on individual test usually have a flow capacity of 500 to 1000 gpm.

Class C: Hydrants that on individual test usually have a flow capacity of less than 500 gpm.

Capacities are to be rated by flow measurements of individual hydrants at a period of ordinary demand. When initial pressures are over 40 psi. at the hydrant under test, the rating is to be based upon 20 psi. residual pressure, observed at the nearest hydrant, connected to the same main, from which no water is being drawn. When initial pressures are less than 40 psi., residual pressures shall be at least half of the initial.

2. The following is the capacity-indicating color scheme:

2.1 *Public Hydrants:* All barrels are to be painted chrome yellow except in cases where another color is desired. The tops and nozzle caps of the classes as outlined in Sec. 1 are to be painted as follows:

Class A—green
Class B—orange
Class C—red.

2.2 *Private Hydrants:* Within private enclosures, the marking is to be at the discretion of the owners. When in public streets, they should be painted to distinguish them from public hydrants.

3. All location markers for flush hydrants should carry the same color background as stated above for class indication, with such data stenciled or painted thereon as may be deemed necessary.

4. The colors shall signify only the approximate capacity of the individual hydrant as tested alone and not its capacity when more than one hydrant in the vicinity is in use. The marking of the hydrant is not to be considered as in any way guaranteeing the capacity indicated by the color.

NOTE: These specifications were adopted by the American Water Works Association at its 1937 Convention at Buffalo and were published in the April 1937 JOURNAL, p. 449.

The standard color scheme duplicates, in essentials, similar plans adopted by the Maine Water Utilities Assn. in 1929, by the New England Water Works Assn. on March 21, 1934, and by the National Fire Protection Assn. on May 14, 1936.

Auxiliary Water Supplies for Emergency Service

By Earl L. Holloway

THE value of auxiliary water supplies is not confined solely to their uses when some part of the regular system is put out of service or rendered inadequate through bombing incidents and other acts of the enemy, but must be considered to extend to all operating conditions. Obviously the need for auxiliary water supplies and the types best suited to care for such needs will vary among different cities, depending upon the nature of the regular source of supply (ground or surface), the number of production centers through which water can be supplied to the distribution system, the adequacy of sources of supply to meet maximum demands, the location of plants in relation to probable target areas, the number and capacity of private supplies which might be used in emergencies, the ability to get critical materials, the cost of the projects, and many other factors. The head of every water works knows the weak points of his system as far as normal operations are concerned and no doubt has made every possible effort to overcome these weaknesses in the most practical and feasible manner. In addition to these considerations, however, he should take a most pessimistic view regarding the possible damage which could be inflicted upon his water system in the event that it is subjected to bombing attacks and should determine how the needs of his city can best be supplied under such conditions.

Before deciding what steps should be taken to provide an emergency auxiliary water supply, an attempt should be made to visualize the damage that might be done to the treatment plant and pumping station in the event that the city is attacked by enemy planes carrying high explosive bombs. Recent literature has indicated that water works stations in England have pretty generally escaped serious damage from bombing. Some engineers seem to feel that this fortunate circumstance may have been due to the location of many water works plants away from target areas, to the protection afforded by anti-aircraft guns and to clever camouflage. Norman J. Howard, writing in the September 1941 issue of the JOURNAL,* has pointed out that, "with reasonable defense against air attack, the bombing . . . becomes a random activity, and, given this random bombing, it is a matter of mathematical probability whether a water works station or main will be hit." This in-

A paper presented on April 21, 1943, at the Michigan Section Meeting, Ann Arbor, Mich., by Earl L. Holloway, Supt., Div. of Water Supply, Flint, Mich.

* Defense of Water Supply Works. Jour. A.W.W.A., **33**: 1475 (1941).

formation is comforting, but the author still is of the opinion that the greatest possible precautions should be taken to protect each plant, as if it were the primary target of enemy attack.

Program for Flint

In Flint, Mich., it has been the earnest desire of the water department management to develop an emergency auxiliary water supply which could not easily be destroyed by enemy bombers and which at the same time would eliminate the danger of a shortage of water due to low river flows or lack of filter capacity, as well as to improve the quality of the water during periods of high temperatures and taste and odor troubles, which have affected the regular source of supply periodically. All things considered, it seemed that the most practical way of accomplishing the desired results was through the development of an underground well supply capable of producing, at least for short periods of time, 10 to 12 mgd., i.e., approximately a third of normal consumption. Such a supply would make it possible to improve the quality of the water delivered during periods of excessive taste and odor concentration and to lower the temperatures during periods of extremely hot weather. It would also make it possible to pump from the wells directly into the distribution system, should demands exceed filter capacity, and to furnish at least minimum demands if the present plant were destroyed by enemy action.

In planning for the auxiliary supply for Flint, studies were made of well supplies in and around the city and consultations were held with the State Geologist and with representatives of the State Department of Health. This investigation indicated that, although the rock in the area contained a considerable amount of water, the supply, when taken in large quantities, had such a high chloride content that it was unfit for domestic and commercial purposes, even for short periods of time. It, therefore, became evident that if a suitable supply was to be secured, it would be necessary to locate channel gravel deposits of sufficient depth and area to yield the quantity of water desired. After an exhaustive study of wells in and around the city and consultations with numerous local drillers, together with some test drilling by the city, such a channel was located. The studies have not as yet been carried far enough to determine the full area of the channel or the maximum amount of water it will yield, but the area has been explored for a distance of approximately five miles with satisfactory results.

The water-bearing stratum of sand and gravel varies in depth from 70 to 130 ft. The quality of the water is good and results so far indicate that the quantity will be sufficient to furnish a satisfactory auxiliary supply. There is no assurance, of course, that it will be possible, during the war, to secure the necessary materials for developing this supply, even if the quantity is sufficient, but at least the groundwork has been done and the department is ready to proceed as conditions permit.

Other Development Methods

There are, of course, many other methods of developing auxiliary supplies for emergencies which have been generally recognized by engineers in England and in this country. Most of these methods, including the use of private well and surface supplies, have

been discussed adequately in recent literature, but a few merit further attention. In England, for instance, valuable storage has been made available by the use of basements of buildings which have been destroyed by bombing or removed for other purposes. If protective plans contemplate pumping water from such surface supplies directly into the distribution system, approval should be obtained in advance from representatives of the State Department of Health and their recommendations as to treatment, which will probably include heavy chlorination, should be followed rigidly. Such treatment should be carried on only under the supervision of competently trained health officials, laboratory technicians or licensed water plant operators.

The fire chief and water department superintendent in each city should make a co-operative survey of all such surface supplies in their city and develop plans for their maximum use should the need arise. Such plans should include the construction of driveways, piers or wharves at the most advantageous places, as such facilities are necessary to permit the fire department to locate their pumping equipment where it can pump directly from such supplies.

NBFU Recommendations

The National Board of Fire Underwriters * has published the following information regarding the use of auxiliary and static water supplies:

"Where streams, rivers and ponds are available, the problem of obtaining an additional supply is not a serious one, and usually means the installation of pumps with adequate provisions for power and for men to operate the equipment. With such a source, however, there is serious danger that the water is badly polluted and, as such, great care must be taken in its use to prevent the possible contamination of the domestic water supply. *The National Board of Fire Underwriters has gone on record as opposing the use of inter-connections between a polluted supply and a normal city domestic supply. We believe this idea should be upheld even under war conditions* [*italics ours*]. This means that if the polluted supplies are to be used, an independent system of mains and hydrants should be installed and great care would have to be taken in regard to the use of both supplies for automatic sprinkler protection. The shortage of material makes such a secondary system out of the question in most cases. The answer is that piers or wharves should be provided to permit fire department pumpers to take water direct from such sources and to deliver it through hose lines.

"The ideal form of storage to independent plants and also for cities and towns is the elevated tank or the storage reservoir located on high ground. The storage reservoir is still a feasible proposition, but the elevated tank is practically out of the picture. It is still possible to get wooden tanks and it may be feasible to build concrete standpipes.

"Under present conditions about the only form of local storage which can be obtained is that in tanks located on the ground and furnishing suction supply to plant fire pumps with emergency connections by which fire department pumpers could take supply. In fact, any storage, whether elevated or ground, might well be provided with

* Auxiliary and Static Water Supplies. National Board of Fire Underwriters Bul. No. 150 (Aug. 1942).

a connection through which a fire engine could take supply. In building ground storage, it is preferable to have the normal water service a few feet above ground as otherwise the stored water might be polluted by seepage of ground water.

"The real question to be considered is the size of this ground storage. A tank 10 ft. in diameter and 10 ft. high will hold slightly less than 6000 gal. of water, which means that it could furnish supply to a 500-gpm. pump for only 10 min. A tank 50 ft. in diameter and 10 ft. high can supply a 1000-gpm. pump for 2½ hr. It is probable that this ground storage will be rectangular; such storage, if 30 ft. by 50 ft. by 10 ft., will hold 120,000 gal., which would permit a 1000-gpm. rate of delivery for 2 hr. There are many plants where it would not be at all unreasonable to expect four or five engines to be called into service, and it would not be at all unreasonable to expect a fire in such a plant to last five hours or more. Under these conditions, suction storage would have to be over 1 mil.gal., which would mean a reservoir approximately 300 ft. by 60 ft. by 10 ft.

"In the recent construction of an airplane factory, where adequate supply to a sprinkler system was desired and elevated storage was out of the question because of the danger to the fliers, a rather unique pressure tank was constructed. This consisted of a sphere set on the ground and large enough to have a capacity of 100,000 gal. The actual water capacity was 60,000 gal., the remaining volume being taken up with compressed air under approximately 80 psi. pressure.

"In considering auxiliary water supplies, some thought must be given to the types and kinds of pumps which can be installed. The ideal would be to provide diesel-engine-driven pumps, as these would give not only a reserve in pumping capacity, but also a source of power, as the normal pump would probably be electrically driven or steam driven. It is practically impossible to obtain diesel engines; a very satisfactory substitute is available in gasoline engines. In recent years, a number of manufacturers have developed centrifugal pumps which can be used with high speed automotive engines such as the Ford, Chevrolet and Chrysler. These pumps are connected direct to the engine and take up very little space. They have capacities of 500 to 600 gpm. at 120 psi. pressure and can deliver up to one-half their capacity at 200 psi. pressure. They are simple in operation and have proved very dependable in connection with fire department use. The principal trouble at the present time would be in getting delivery. These auxiliary pumps should not be placed in the plant nor in the same room with the regular pumps. This is partly to offset the danger of both classes of pumps being put out of service, but also because of the hazard introduced by the use of gasoline. A small metal-clad or masonry building can be erected over the pumps and the building can be left without heat, although heat would be desirable. It is possible to use an antifreeze solution in the cooling water of the engine."

San Francisco Supplies

San Francisco has probably developed the use of cisterns and swimming pools for auxiliary water supplies to a greater extent than any other American city. The value of underground storage cisterns in this city was indicated in the 1906 conflagration, for it is believed that the availability of such a

reserve supply, at that time, in the districts affected by the earthquake, would have enabled the fire department to extinguish the various fires in their incipient stages and, thus, to prevent the conflagration. Plans to prevent a recurrence of this conflagration provided for the installation of a cistern water supply and a separate system of high-pressure mains for fire protection; and the adoption and carrying out of these plans made the city almost unique among American municipalities in having available a bomb-proof system of fire protection.*

Actually, the history of the San Francisco cistern system antedates by more than fifty years its development after the 1906 conflagration. Prior to 1852, when the city was first being developed, brick and lumber underground cisterns were used for fire protection, as the public water supply was not adequate for this purpose. During the half century following 1852, 66 brick cisterns, with storage capacities of between about 9000 and 90,000 gal. were constructed, mainly in the northeastern section of the city.

The value of these cisterns apart from the regular supply was not appreciated, however, so when the city water supply system was improved and enlarged to include the placement of many hydrants on the water mains throughout the built-up area, the cisterns were neglected. In time they became filled with debris and their locations were, in many cases, forgotten.

In 1908, and again in 1933, the citizens voted to construct an auxiliary fire protection system entirely independent of the domestic supply. Total bond issues authorized for this construction amounted to $7,200,000, the greater part of which was used to construct the separate high-pressure system. A portion of the money, however, was diverted to redevelop the cistern supply.

With this money, 51 of the 66 neglected brick cisterns were repaired and restored to duty and a number of new ones constructed. Storage capacities of the restored cisterns ranged from 8600 to 95,000 gal., with a total combined capacity of 1,651,000 gal. The new cisterns were constructed of reinforced concrete, after a standard design, each having a capacity of 75,000 gal. They are circular in shape, with an inside diameter of 30 ft. and vertical side walls 10 ft. high. They have saucer-shaped bottoms which dip down 3 ft. in the center and their domes rise 5 ft. At the center of each dome and at one side of each dome are located 2-ft. circular manholes over which iron covers are placed at street surface.

To utilize the water in these cisterns, a suction hose is dropped through a manhole and connected to a fire pumper. At least two pumpers can operate at any cistern with a suction hose in each manhole. The cistern supply will provide more than an hour's supply for two pumpers, each drawing 500 gpm.

No pipe connections to the cisterns have been made, so that they are free to move with the earth as self-contained units, hose lines being used to fill them. An incident during the construction of the cisterns proved the value of this provision, when, due to a rainstorm, one of the cisterns was floated six feet off its foundation. When this unit later settled back on the foundation no injury or leakage was discernible.

The cisterns have been located at street intersections and their locations indicated on the surface by a 30-ft.

* The following information was abstracted from: CASEY, JOHN J. Emergency Cistern Supply. W.W. Eng., **95**: 658 (1942).

diameter ring of basalt blocks set in the pavement. As far as possible, the system has been laid out to place them not more than 1000 ft. apart. In the construction, ground conditions at each location were studied and special designs made to fit these conditions as necessary. Specific locations were also adjusted to minimize the disturbance of existing underground utilities.

Construction costs for the new reinforced concrete cisterns have averaged about $6000 each. Of the new cisterns, 85 were financed by the bond issue approved in 1908. One was later constructed from budget funds in 1921 and 20 were financed by the bond issue of 1933. All but three of the cisterns are located within an area of 20 sq.mi. The combined storage capacity of the 106 concrete cisterns is 7,950,000 gal., which, added to the capacity of the restored units, gives the city a total cistern storage capacity of 9,601,000 gal.

In addition to its cistern supply, San Francisco has installed connections to two swimming pools having a total capacity of 280,000 gal., to be used as a reserve supply for fire protection purposes. At the civic center, a cistern and fountain basin storage of 335,000 gal. is also available for fire fighting and on private property, one reinforced concrete cistern of 75,000 gal. capacity is available for such use.

Over and above this static supply, the city now has a separate high-pressure fire system, financed by the greater part of the $7,200,000 in bonds authorized by the voters in 1908 and 1933. This system was placed in service in 1913 and covers an area of slightly more than 14 sq.mi., which includes the entire congested value district, practically all important mercantile and industrial areas and many closely built frame residential districts in the northeastern part of the city.

The fire protection distribution system is constructed of cast-iron mains and is used exclusively to supply the hydrants on the line. The supply normally is taken by gravity from two tanks at moderate elevations. A storage reservoir at high elevation is located southwest of the area served by the system and is used to replenish the tanks or to increase pressure in the mains. Two pumping stations, one northwest and one southeast of the area, draw their supply from San Francisco Bay and are held in readiness for emergency use. In addition, six manifolds through which fireboats can pump water into the system are also maintained.

The 11-mil.gal. supply reservoir is at an elevation of 759 ft. above sea-level. The two storage tanks have a combined capacity of 1¼ mil.gal. and are located at elevations of 494 and 369 ft. Each pumping station is equipped with four 4-stage turbine pumps, driven by steam turbines and capable of delivering 3000 gpm. against a head of 300 psi.

In addition to these two auxiliary water supply systems for fire protection, San Francisco has several separate sources for its public water supply, making it foremost among American cities in its potential ability to combat the fires that will be caused if enemy bombing occurs.

Inventory of Possibilities

As was pointed out previously, many English cities have developed auxiliary emergency water supplies by converting the basements of buildings demolished by bombing attacks. Probably not many American cities now have basements which could be used for such purposes, but every manager or super-

intendent of a water department should become familiar with what was accomplished in England and should be prepared to benefit by this experience if bombings occur in this country.

Many cities have available industrial supplies which can be utilized for fire fighting or for domestic purposes in the event that the municipal supply is damaged by enemy action. Every such possibility should be thoroughly explored, and the approval and recommendations of the State Department of Health obtained. If the supply is approved for pumping into the distribution system and the operating characteristics of the pumps, relative to capacity and pressure, warrant such action, plans should be developed and the necessary materials secured to make such physical connections.

It is advisable to take an inventory of all pumping facilities, particularly of portable pumps, owned by industries, contractors, highway commissions, etc., and to make a record of the capacity, operating pressure, physical condition and other pertinent information, as well as to note the best possible use to which such equipment might be put in an emergency.

Health Considerations

In the effort to provide emergency auxiliary water supplies, the health of the citizens of the community served should always be considered of first importance. The State Department of Health's regulations should be complied with fully, and if, in the surveys of private pumping facilities, cross-connections which do not comply with these regulations are found they should be eliminated without delay. In Michigan, health regulations provide, among other things, that:

"No physical connection shall be installed or maintained between lines carrying a potable public supply and pipes, pumps or tanks supplied or possible of being supplied, from any non-potable source. Where dual supplies are necessary or desired, lines carrying water from the public supply must be protected against back-flow of polluted water by means of an atmospheric gap of not less than six inches. This may be accomplished by an elevated tank with or without booster pump or a reservoir from which water is pumped. In every case, the inlet line to the tank carrying potable water shall discharge at least six inches above the maximum possible high-water level of the tank or reservoir as the case may be.

"Service connections between a potable public supply and a potable private supply are permissible with the following provisions:

A. That the approval of the owners of the potable public supply and the Michigan Department of Health be obtained in writing.

B. That the quality of the private supply be under the supervision of a laboratory. For a well water supply, at least one bacteriological sample shall be analyzed each month from each source of supply. For a treated surface water supply, daily tests by a local laboratory shall be made.

C. That regular inspections of the service connections and collection of water samples for bacteriological examination shall be made by those in charge of the potable public supply to which the connection is made, or by the local health department.

D. That, if the potable private supply is from wells, their construction and location shall meet the minimum requirements of the Michigan Department of Health as set forth in Engi-

neering Bulletin No. 19 on 'Well Water Supplies for Municipalities.'

E. That the connection shall be provided with at least one gate valve and one swing check valve so arranged that the check valve may be tested for leakage by means of a drain valve. The specifications for the gate and swing check valves shall be those prepared by the Associated Factory Mutual Fire Insurance Companies, Boston, Mass."

Reserve Equipment and Supplies

All available chlorine equipment and chlorine stocks in the local community should be located and cataloged. The capacity and type of equipment should be listed and plans developed for its possible use in case of an emergency. Such equipment may be found at swimming pools, sewage disposal plants, paper mills and other industrial plants.

All plans for the use of emergency water supplies should be developed with the fullest co-operation of the local and state health officials and the fire chief. In Flint, plans provide that, in the event of failure of all, or a portion, of the municipal supply, the Health Department will assume responsibility for delivering potable drinking water to the citizens. This is particularly desirable because all private wells in the city are under the jurisdiction of the Health Department and because of their contacts with dairies and private bottling works and their knowledge of how properly to sterilize tank wagons to make them safe for delivering potable water. Such a plan also leaves the Water Department free to devote all its energies to restoring the municipal supply to normal operating conditions.

Relative Resistance of Coliform Organisms and Certain Enteric Pathogens to Excess-Lime Treatment

By Elsie Wattie and Cecil W. Chambers

THE use of the excess-lime method in water purification has been tried in many cities with very satisfactory results. A study was made by Hoover (1) of results obtained in six Ohio cities using this method. The average bacterial load of the raw water of these cities was 2274 *Esch. coli* per 100 ml.; this was reduced to an average of 0.6 *Esch. coli* per 100 ml. using the excess-lime method, with a contact period varying from 3.5 to 23.2 hr. The important factors noted by Hoover as governing this method of water sterilization were: (1) the quantity of excess lime used; (2) the time of reaction or contact period; and (3) the quantity of mud and organic matter and the number of bacteria present in the raw water. At the Ohio plants studied, where lime was added in sufficient amounts to produce a hydrogen ion concentration greater than pH 9.5, *Esch. coli* were not found in 50-ml. portions; but, with a pH of less than 9.5, *Esch. coli* were found in all samples, except one, in the 10-ml. portions. The excess-lime treatment was found to kill 99.93 per cent of the coliform organisms in 5 hr. when 1 gpg. was added and 100 per cent in 5 hr. using 3 gpg. Laboratory experiments conducted showed that this treatment was effective when *Eberthella typhosa* organisms were present in the raw water, but no specific results were given.

Streeter (2) studied the efficiency of the excess-lime method by comparing the parallel results obtained using a raw water with and without the addition of lime, the treatment otherwise being the same—consisting of coagulation, sedimentation, rapid sand filtration and post-chlorination. The average *Esch. coli* index of the "lime-treated" applied water was 624 per 100 ml. with a pH of 10.2 and for the "untreated" applied water, 3530 per 100 ml. with a pH of 6.7. The raw water had an initial coliform index of 29,700 with a pH of 7.3. Greater reductions were observed in the total numbers of bacteria present per milliliter. Streeter concluded that the number of bacteria in the raw water diminished progressively with the increased amounts of causticity, not only in the applied water, but also in the filtered and chlorinated waters, and that the bacterial efficiency of the excess-lime process as a whole was definitely related to the intensity of the treatment. The use of the excess-lime method as a means of disinfecting water appeared to be more difficult to control and less

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consistent in its daily results than the use of chlorine, but was found to aid in purifying polluted hard waters.

Various Ohio water purification plants treating waters with a wide range of hydrogen ion concentrations were selected for study by Scott and McClure (3). The amount of lime used at these plants varied from an amount sufficient to produce complete lime softening to zero. The results show *Esch. coli* to be absent from the 50-ml. portions from plants with waters of low hydrogen ion concentration (pH 10.44–9.29), but present in the 10-ml. portions from waters of higher hydrogen ion concentrations (pH 7.35–9.14). Temperature changes had a marked effect; for example, a temperature increase from 8°C. to 27°C. shifted the lethal pH from 10.32 to 9.89. It was concluded that a pH of 10.0 to 10.3 was sufficient to provide a reasonable margin of safety with the limiting value in the neighborhood of pH 9.5. Hoover (4) states that a natural water treated with the theoretical amount of lime required to soften it will have a pH value of approximately 9.5, the limiting value given by Scott and McClure. During flood and high water conditions at Columbus, Ohio, chlorine treatment was discontinued and excess-lime treatment used, with a caustic alkalinity of 20 ppm. in the filtered water.

Edwards (5) reported that the Ohio River raw water supply for the city of Ironton, Ohio, contains industrial wastes as well as sewage pollution. When lime was added to give 20–25 ppm. causticity a decided reduction in the bacterial population was noted. The *Esch. coli* index was reduced from 20,000–40,000 per 100 ml. to approximately 100 per 100 ml. An increase in turbidity of the raw water lowered the efficiency of bacterial removal in the primary settling basin. No trouble has been experienced due to the presence of algae since the initiation of excess-lime treatment.

The suspension of the use of chlorine and the substitution of excess-lime treatment at Cincinnati, Ohio, was reported by Bahlman (6) as being a result of the presence of taste-producing industrial wastes in the raw water. Bahlman concluded that it was not necessary to reach the caustic point to produce water free, or practically free, from *Esch. coli*. Such waters were produced by converting 50–80 per cent of the bicarbonates in the filtered effluent into monocarbonates or by attaining a pH of 9.4 to 9.5. Such reactions gave markedly better *Esch. coli* removals than pH 9.0–9.3, with only 30–45 per cent of total alkalinity present as normal carbonates.

The use of excess lime as a sterilizing agent which avoids phenolic tastes that would be accentuated by the use of chlorine has been studied by various water plant operators. Edwards (7) reports that the use of lime at Ironton, Ohio, has reduced the bacterial content and prevented excessive loads upon other purification processes and has effected a degree of bacterial removal great enough to permit minimum chlorine application at times when phenols are present in the raw river water. At Youngstown, Ohio, the use of lime was studied by Van Arnum (8), who states that the use of lime improves coagulation and permits the use of smaller alum doses. He points out too that lime is useful to precipitate the large amounts of iron contained in the raw water and to neutralize the free mineral acids present, as well as acting to prevent corrosion under high acid conditions. Finally, he reports that, when lime was used as a sterilizing agent, phenolic

tastes, accentuated by chlorine, were avoided.

The information obtained from this brief survey of the literature suggests quite clearly that the excess-lime method of water treatment might be substituted for pre- and/or post-chlorination, without a marked loss in bactericidal efficiency. As the possibility of a chlorine shortage, or of conditions in which chlorine would not be available, appear to be indicated, it seemed pertinent, in connection with the studies in progress at the Stream Pollution Investigations Laboratory at Cincinnati, to investigate the bactericidal efficiency of a number of agents and processes. Accordingly, laboratory tests were instituted to determine the bactericidal efficiency of the excess-lime method of water treatment as exhibited against the common water-borne pathogens and the standard indicator organisms—the coliform group. This report presents the information which has been obtained concerning this phase of the study.

Methods

For a standard suspending medium, de-chlorinated tap water was prepared by adding a sufficient amount of sodium sulfite (Na_2SO_3) crystals to neutralize any residual chlorine present and sterilizing the water by autoclaving in 8-liter serum bottles. Liter portions were aseptically transferred to sterile liter flasks fitted with rubber stoppers and paper caps. Control tests were made for residual chlorine present, either as chlorine or chloramine, and also for any excess of Na_2SO_3 present. A saturated solution of calcium hydroxide ($Ca(OH)_2$) was added, in the following amounts, to a series of six flasks: 0.0 ml., 8.5 ml., 13.0 ml., 30.0 ml., 55.0 ml. and 70.0 ml. Similar amounts of the sterile de-chlorinated water were previously removed from each of the corresponding flasks in order to maintain an equal final volume in all flasks. A bacterial suspension was prepared using the growth from an agar slant, incubated at 37°C. for 24 hr., of the organism being studied. The bacterial suspension was prepared in such a manner that it would contain approximately 1,500,000 organisms per 1 ml., thus giving, when 1 ml. of this suspension was added to each of the liter portions in the test flasks, an initial bacterial population in the flask of about 1500 per ml.

After thorough mixing (about 1 min.) total bacterial counts were made by planting a series of agar plates; and a portion was removed for hydrogen ion and alkalinity determinations. When the test organism was a pathogen, the portion to be used for the pH and alkalinity determination was removed before the culture was added. In such experiments, only 500 ml. of water, instead of 1 liter, was used, other factors being reduced accordingly. Bacterial examinations were made at various time intervals, usually at the start and after 1, 30, 60, 120 min. and thereafter at hourly intervals up to the tenth hour. All experiments were carried out at room temperature (20°–25°C.) except in a few instances when tests were made at low temperatures (0°–1.0°C.). These instances are noted herein as presented.

In a few of the early experiments the saturated lime solution was sterilized and introduced aseptically after adding the bacterial suspension. This practice was later omitted and raw $Ca(OH)_2$ was used exclusively because the tests revealed that no interfering organisms were present in the lime solution and that sterilization reduced its bactericidal power to a marked degree without a proportionate decrease in pH.

Several strains of pathogenic and non-pathogenic bacteria were selected for this study, including four strains of *Escherichia coli,* two of *Aerobactor aerogenes,* two of *Pseudomonas pyocyaneus,* two of *Eberthella typhosa* and two of *Shigella dysenteriae.* The four strains of *Esch. coli* were all typical, *thella typhosa*—one isolated from sewage and giving all of the typical reactions of this group and the other isolated from blood of a case clinically typical—and by two strains of *Shigella dysenteriae,* both isolated from feces during an epidemic which occurred during the previous year.

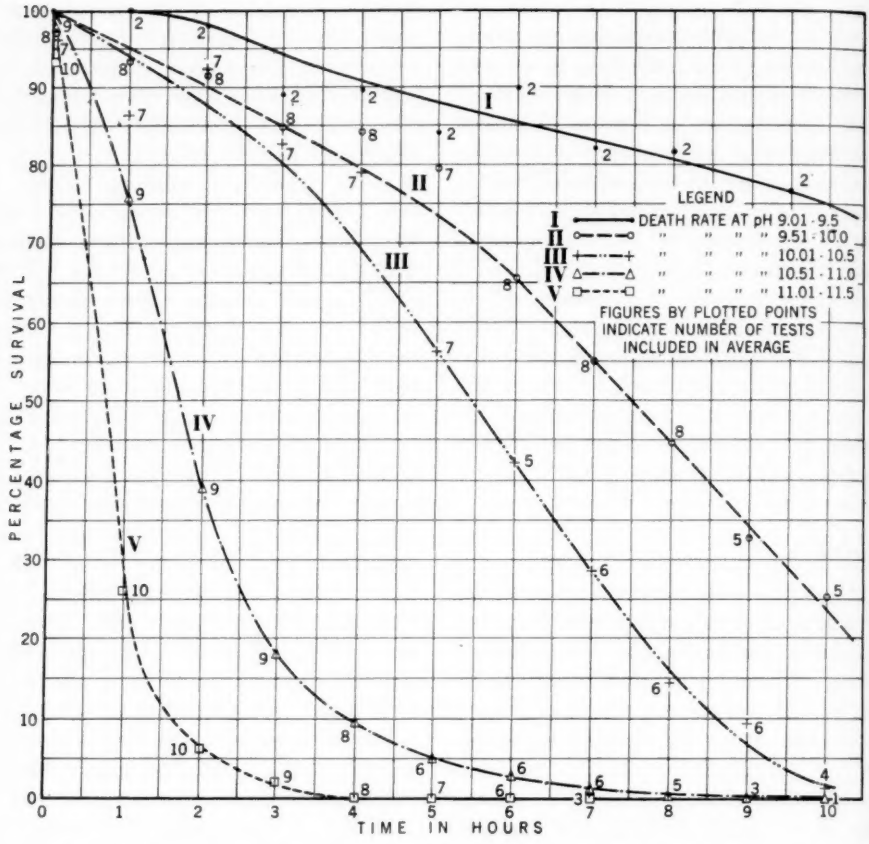
PERCENTAGE SURVIVAL
TIME IN HOURS
LEGEND
I DEATH RATE AT pH 9.01 - 9.5
II " " " 9.51 - 10.0
III " " " 10.01 - 10.5
IV " " " 10.51 - 11.0
V " " " 11.01 - 11.5
FIGURES BY PLOTTED POINTS INDICATE NUMBER OF TESTS INCLUDED IN AVERAGE

FIG. 1. Average Death Rate of *Esch. coli* Strains at Various pH Ranges

isolated within the last few years. Two typical *Aer. aerogenes* strains were used, one of which had been isolated from feces. The water-borne, questionable pathogenic group was represented by two strains of *Ps. pyocyaneus.* The true intestinal pathogens were represented by two strains of *Eber-*

Colonies which developed from surviving organisms, prior to a 100-per cent kill, were picked from the plates to appropriate media for confirmation of the specific organism being studied. This was carried out in all experiments as a check on contamination and to determine if the excess-lime treatment al-

tered the ability of the test organism to produce the typical reactions of the specific group.

The hydrogen ion concentration and total alkalinity determinations were made in the Stream Pollution Investigations Chemical Laboratory, which co-operated throughout in this phase of the study. The hydrogen ion concentrations were determined electrometrically. These readings were checked frequently on another similar apparatus and were controlled by frequent determinations made on standardized buffer solutions. Total alkalinity was determined according to *Standard Methods* (9) procedure.

Results

The basic data obtained in this study have been compiled in a series of tables. For convenience in studying the results and to show more clearly the trend of the average results, the basic data are presented here in the form of graphs and summary tables only.

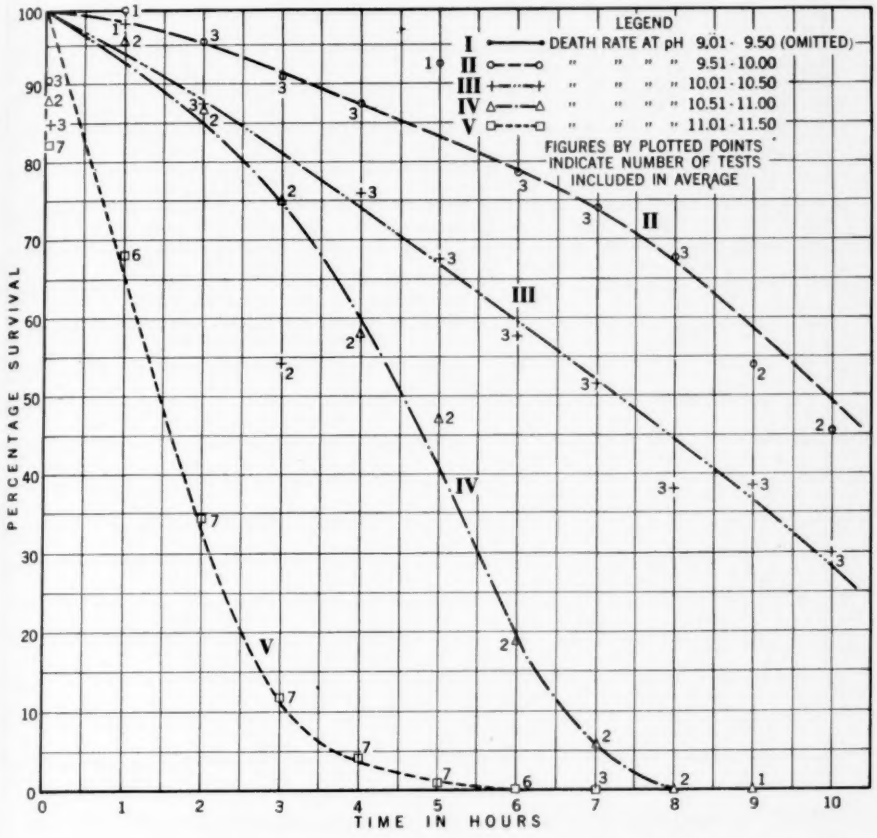
LEGEND
I DEATH RATE AT pH 9.01 - 9.50 (OMITTED)
II " " " " 9.51 - 10.00
III " " " " 10.01 - 10.50
IV " " " " 10.51 - 11.00
V " " " " 11.01 - 11.50
FIGURES BY PLOTTED POINTS INDICATE NUMBER OF TESTS INCLUDED IN AVERAGE
PERCENTAGE SURVIVAL
TIME IN HOURS

FIG. 2. Average Death Rate of *Aer. aerogenes* Strains at Various pH Ranges

In presenting graphically the data obtained, it was found convenient to treat the data in groups, by establishing a series of pH ranges. This was necessarily the case, as it was not possible to reproduce exactly (without prolonged manipulation, which would require time and interfere with the results of the tests) a given pH by the

addition of one measured volume of the saturated lime solution. Consequently, for the graphical presentation, the results were grouped as follows: Any result obtained from a sample with a pH in the range of 9.01 to 9.50 was placed in Group I, and only the

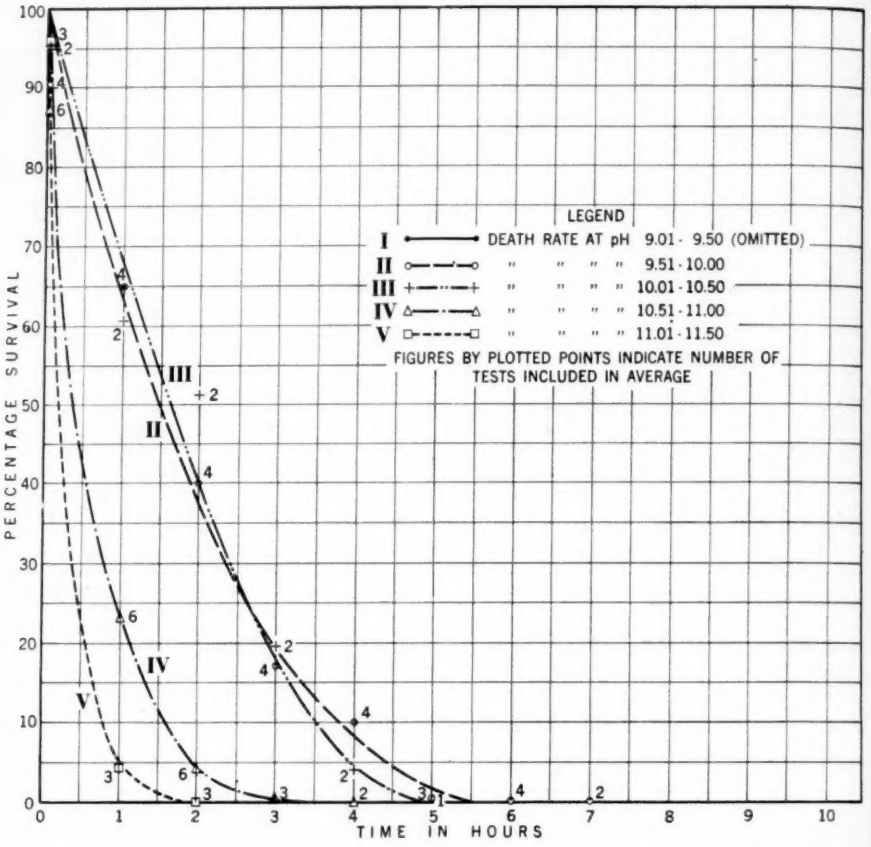
LEGEND
I DEATH RATE AT pH 9.01 - 9.50 (OMITTED)
II " " " " 9.51 - 10.00
III " " " " 10.01 - 10.50
IV " " " " 10.51 - 11.00
V " " " " 11.01 - 11.50
FIGURES BY PLOTTED POINTS INDICATE NUMBER OF TESTS INCLUDED IN AVERAGE
PERCENTAGE SURVIVAL
TIME IN HOURS

FIG. 3. Average Death Rate of *Ps. pyocyaneus* Strains at Various pH Ranges

Group I plotted points were considered in establishing the form of Curve I, in each of the figures. Similarly the results obtained from samples with a pH in the range 9.51–10.00 were placed in Group II and determined the trend of Curve II; the range pH 10.1–10.50 constituted Group III, Curve III; pH 10.51–11.00 for Group IV, Curve IV; and pH 11.01–11.50 for Group V, Curve V. This grouping arrangement necessarily means that some points considered in separate curves might be very close to each other in pH values; for instance, a result from pH 9.50 would be considered in Group I whereas a result from pH 9.51 would be in Group II. For convenience in a summarized presentation, however, this arrangement seemed essential and all data presented in all figures have been considered in this manner.

The results obtained with the four strains of *Esch. coli* using the methods outlined are presented graphically in

Fig. 1. It is noted that the *Esch. coli* death rate is decidedly slow throughout the 10-hr. period of observation in the hydrogen ion concentration range of pH 9.01–9.50 (Group I) and in the pH range 9.51–10.00 (Group II) up to the sixth hour. After the sixth hour there appears to be an acceleration in the *Esch. coli* death rate in the latter group. In the pH range 10.01–10.50 (Group III), there is an increase in the death rate over that observed in Groups I and II after the third hour. A possible exception may be noted in the tendency toward a slight lag after the eighth hour. In the pH range 10.51–11.0 (Group IV) and in the pH range 11.01–11.50 (Group V), there is a sudden drop in *Esch. coli* numbers during the first 2–3 hr. This is more marked with the decrease of acidity in Group V, but this decrease gradually tapers off after the fourth hour at pH values up to 11.0 and after the second hour with pH values up to 11.5.

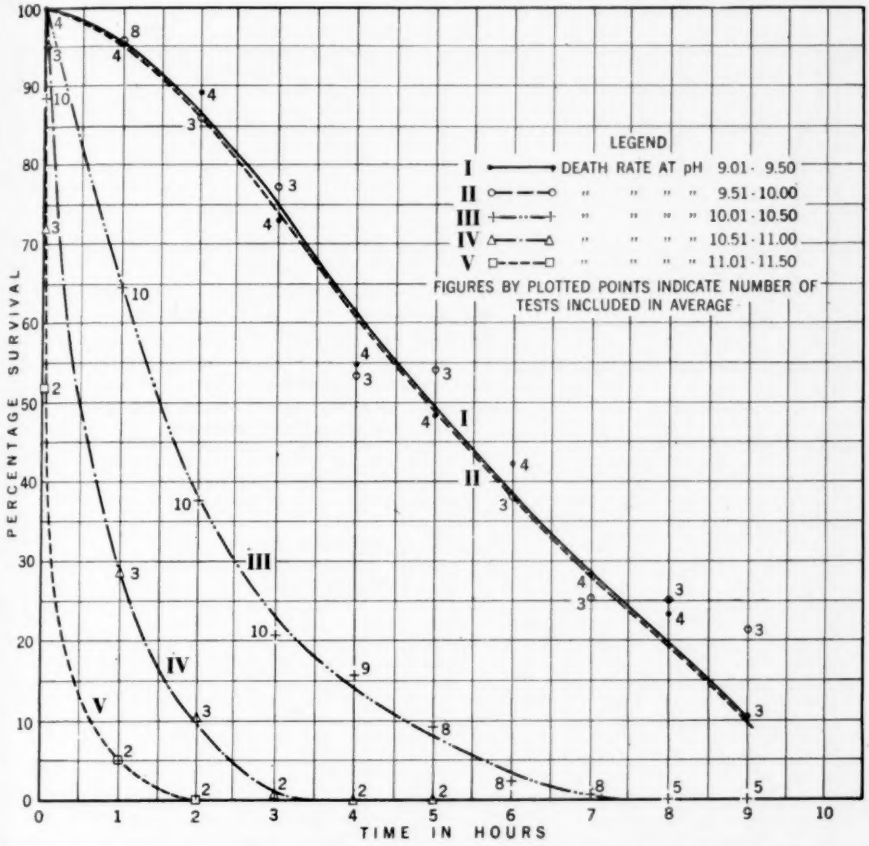
LEGEND
I DEATH RATE AT pH 9.01 - 9.50
II " " " " 9.51 - 10.00
III " " " " 10.01 - 10.50
IV " " " " 10.51 - 11.00
V " " " " 11.01 - 11.50
FIGURES BY PLOTTED POINTS INDICATE NUMBER OF TESTS INCLUDED IN AVERAGE
PERCENTAGE SURVIVAL
TIME IN HOURS

FIG. 4. Average Death Rate of *Eberthella typhosa* Strains at Various pH Ranges

Data on the results obtained with the two strains of *Aer. aerogenes* are shown in Fig. 2. With these organisms much slower death rates were obtained in all pH ranges than were observed with the *Esch. coli* organisms studied. No observations are recorded with *Aer.*

aerogenes in the pH range of the highest acidity, pH 9.01–9.5 (Group I), as this range was not effective with this organism. With *Aer. aerogenes* a definite lag in the death rate was observed during the first few hours of the experiments, as was suggested in the *Esch. coli* results; but this lag extended

duce a hydrogen ion concentration in the range of pH 9.01–9.50. In each of the four higher pH ranges obtained, however, there was a marked kill of *Ps. pyocyaneus* during the early stages of each test. This rate continued until about a 95-per cent kill had been obtained. Then, a very gradual decrease

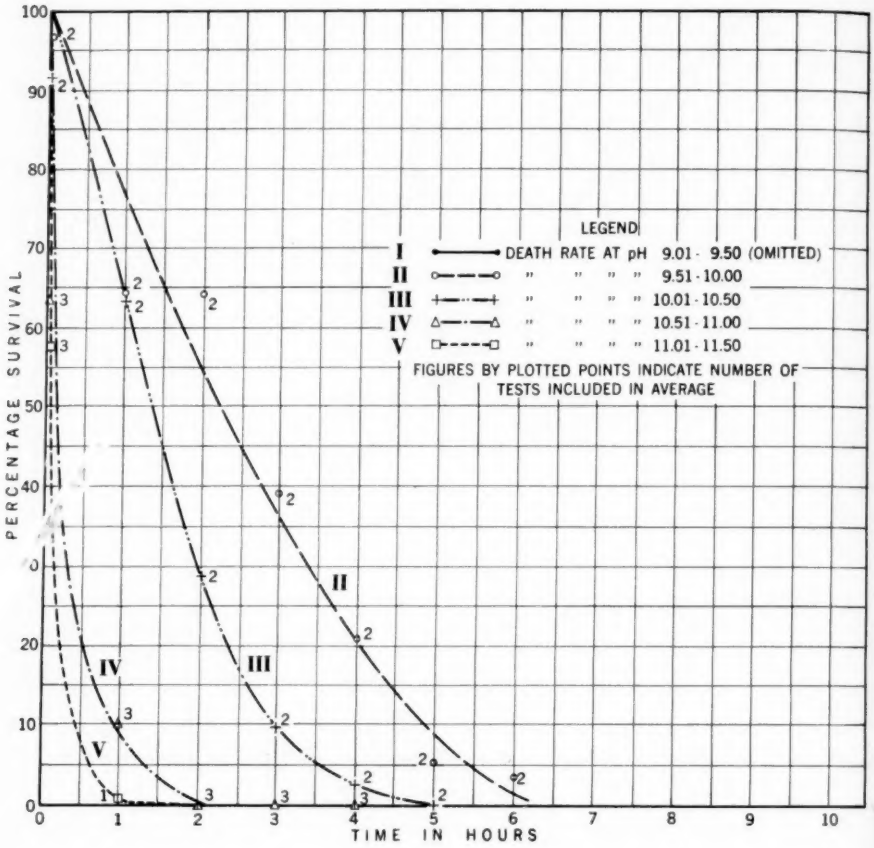
PERCENTAGE SURVIVAL
TIME IN HOURS
LEGEND
I DEATH RATE AT pH 9.01 - 9.50 (OMITTED)
II " " " " 9.51 - 10.00
III " " " " 10.01 - 10.50
IV " " " " 10.51 - 11.00
V " " " " 11.01 - 11.50
FIGURES BY PLOTTED POINTS INDICATE NUMBER OF TESTS INCLUDED IN AVERAGE

FIG. 5. Average Death Rate of *Shigella dysenteriae* at Various pH Ranges

the range of pH 10.51–11.0—much higher than found with *Esch. coli* as the test organism.

much more rapid death rate in all the pH ranges studied was obtained with the two *Ps. pyocyaneus* strains. Unfortunately the amounts of lime solution added in the tests did not produce in the rate of kill was obtained in all cases. The results obtained with *Ps. pyocyaneus* as the test organism are shown in Fig. 3.

The results obtained with the two strains of *Eberthella typhosa* are presented in Fig. 4. From these curves it is noted that, for the pH ranges 9.01-

9.50 and 9.51–10.00, there is a slight lag in the death rate for an hour or two at the start, but, that, thereafter, the death rate increases and continues to progress at a fairly constant rate. When the pH is increased to the range 10.01–10.50 there is a marked kill to about 50 per cent during the first 90 min. of exposure, followed by a more gradual decrease until a 100-per cent kill is obtained in about 460 min. In the two higher pH ranges—10.51–11.0 and 11.01–11.50—there is a very rapid decrease of viable organisms during the first hour, followed by a more gradual decrease. A 100-per cent kill is obtained in the pH range 10.51–11.0 in about 240 min. and in the pH range 11.01–11.50 in 120 min.

With the two strains of *Shigella dysenteriae* used, a rapid kill was obtained in all of the pH ranges studied. In the lower pH ranges—9.51–10.00 and 10.01–10.50—however this rapid rate of kill decreased after 2½–4 hr. and, thereafter, a more gradual death rate ensued. In the next higher pH range—10.51–11.00—a 100-per cent kill was obtained between the second and third hour and in the pH range

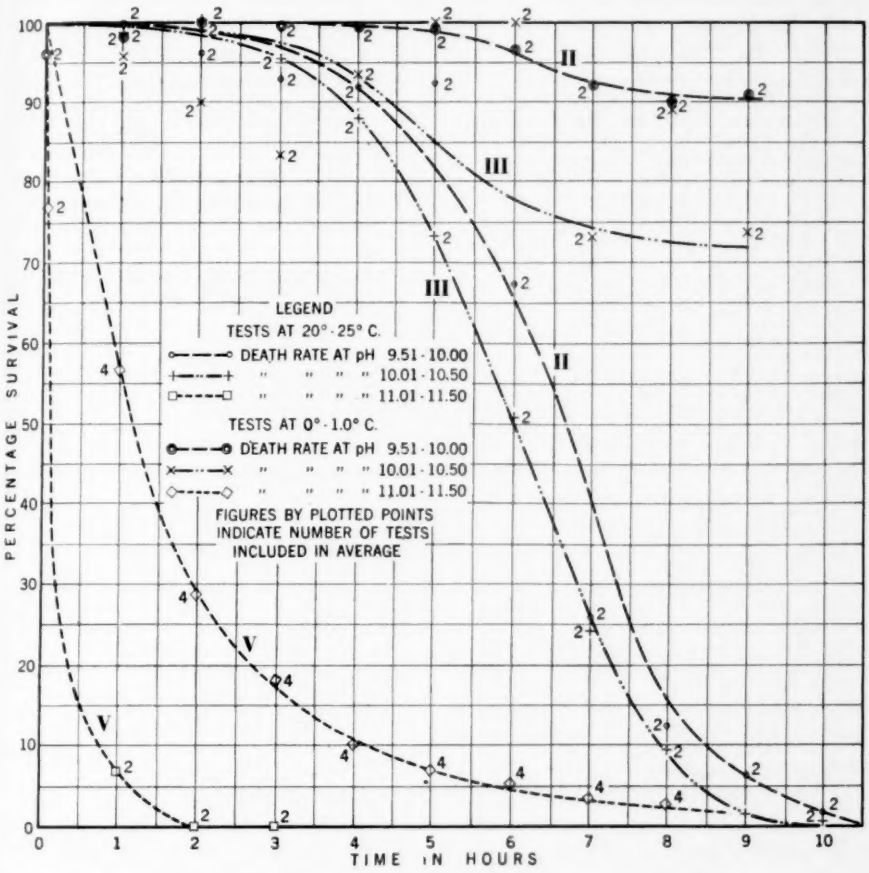

FIG. 6. Death Rate of Typical *Esch. coli* Strain at Various pH Ranges at 0°–1.0°C. and at 20°–25°C.

11.01–11.50, no living organism was found after 75 min. The results are presented in Fig. 5.

The bactericidal efficiency of the excess-lime treatment was determined also at a lower temperature (0°–1.0°C.) with one strain of *Esch. coli* and the strain of *Eberthella typhosa* isolated three pH ranges studied. In the extreme case—the pH range 11.01–11.50—at 20°–25°C., a 100-per cent kill was obtained in 2 hr., while in the same pH range, at 0°–1.0°C., viable organisms were present at the end of 9 hr. In the results at the lower temperature there was a decided lag up to

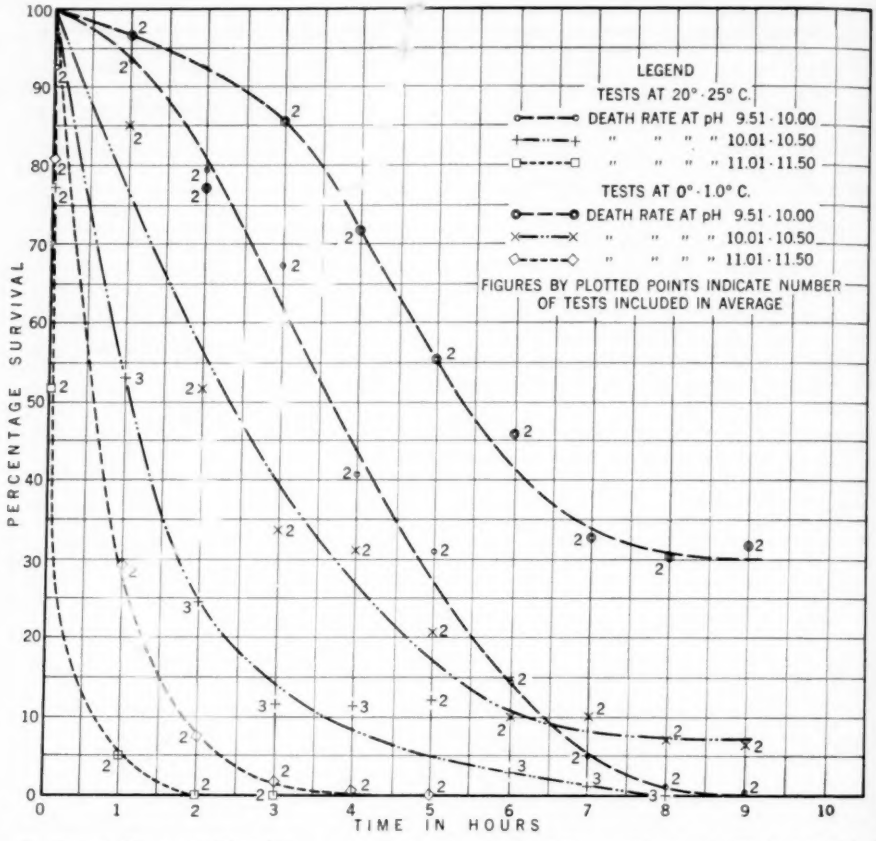

FIG. 7. Death Rate of *Eberthella typhosa* Strain Isolated From Blood of Clinical Typical Case at Various pH Ranges at 0°–1.0°C. and at 20°–25°C.

from the blood of a clinically typical case. The results obtained using *Esch. coli* are shown in Fig. 6. The *Esch. coli* death rate is not as fast in water of parallel pH values at this lower temperature as it was when the tests were carried out at room temperature. This is definitely shown in each of the the fifth hour, with only a 10-per cent kill at the end of the ninth hour in the pH range 9.51–10.0, while in the pH range 10.01–10.50 this lag persisted only about 180 min. In the same pH ranges at room temperature, a corresponding lag in the death rate was observed up to about the third hour and,

thereafter, there occurred a marked acceleration in death rate not observed at the lower temperature.

The differences in the death rate produced by temperature variations when the *Eberthella typhosa* strain was the test organism, though of the same general nature as observed with *Esch. coli*, were not so marked. This organism had a tendency to "hang on" after a high percentage kill had been obtained. The results of this test are shown in Fig. 7 and the time required to obtain a 100-per cent kill of the two organisms studied at low temperature is presented in Table 1.

TABLE 1

Time Required to Obtain 100-per cent Kill of Esch. coli *and* Eberthella typhosa *When Exposed to Various pH Ranges at 0°–1.0°C. and at 20°–25°C.*

pH Range	Time, in min., to Obtain 100-per cent Kill With:			
	Esch. coli at:		*Eberthella typhosa* at:	
	20°–25°C.	0°–1.0°C.	20°–25°C.	0°–1.0°C.
9.01–9.50	—	—	>600	—
9.51–10.0	>600	>600	540	>600
10.01–10.5	520	>600	290	>600
10.51–11.0	480	—	—	—
11.01–11.5	210	355	75	270
11.51–12.0	—	180	50	85

Discussion

Data have been presented to show the death rates of coliform bacteria (*Esch. coli* and *Aer. aerogenes*), one of the *Pseudomonas* genus (*Ps. pyocyaneus*) and two species of enteric pathogens (*Eberthella typhosa* and *Shigella dysenteriae*) when exposed to varying hydrogen ion concentrations as produced by excess-lime treatment, carried out at room temperatures. The relative resistance of these organisms to such treatment processes is of major importance in selecting a criterion for determining the sanitary quality of a water supply. In an attempt to show their relative resistance more clearly, the data of Table 2 have been compiled.

TABLE 2

Time Required to Obtain a 100-per cent Kill With Excess Lime at Various pH Ranges With Indicated Organisms (Tests Carried out at Room Temperature)

pH Range	Time, in min., to Obtain 100-per cent Kill With:				
	Esch. coli	*Aer. aerogenes*	*Ps. pyocyaneus*	*Eberthella typhosa*	*Shigella dysenteriae*
9.01–9.50	>540	—	—	>540	—
9.51–10.0	>600	>600	420	>540	>360
10.01–10.5	>600	>600	300	>540	>300
10.51–11.0	600	>540	240	240	180
11.01–11.5	300	>600	120	120	75

In this connection it should be borne in mind that in these tests an attempt was made to keep the initial concentration of each test organism at about the same number of organisms per milliliter (1000–1500). Consequently, the percentage survival of the pathogens and the coliform organisms are considered here on an equal basis of initial concentration, whereas in natural waters the *Eberthella typhosa* are outnumbered by the coliform organisms by approximately 10,000–100,000 to 1 as estimated by Kehr and Butterfield (10). Thus, under natural conditions it would be reasonable to assume that the *Eberthella typhosa* content would be reduced below the range of an infective dose long before the coliform organisms had been similarly reduced. Consequently, under some conditions, safe waters might be produced by pH ranges of 9.51–10.00 or 10.01–10.50 during a 4–6-hr. contact period.

In Table 2 only the time in minutes required to obtain a 100-per cent kill

is presented. It is noted that the time required to obtain a 100-per cent kill for members of the coliform group of bacteria, at the various pH values, exceeds the time required for a 100-per cent kill of the pathogenic organisms studied, at the pH values of 10.0 and above. This would indicate that using the coliform group as a criterion for judging the safety of a water supply treated by the excess-lime process, with the pH values in the studied range, the water would be safe for human consumption with reference to pathogens of the groups studied if coliform organisms were absent or only present within the limits of the current U.S. Public Health Service Drinking Water Standards (11).

Conclusions

The data obtained from the excess-lime experiments have pointed to the following conclusions:

1. With the pH ranges produced by the use of the excess-lime method of water treatment, a bacterially safe water may be obtained if appropriate adjustments of pH and time of contact are made.

2. The death rate of all the strains tested is increased at higher pH ranges.

3. Higher death rates are observed with the pathogens studied than with the non-pathogenic bacteria in the various pH ranges covered.

4. Temperature influences the rate of kill of the two organisms tested, being depressed at lower temperatures.

5. The results suggest that in the pH ranges 9.51–10.0 and 10.01–10.50, a 100-per cent kill of the pathogens was not obtained during a 6-hr. contact period. The percentage survival of *Eberthella typhosa* (the more resistant of the pathogens studied) at the 6-hr. period, for these pH ranges, was 30.8 and 2.4 respectively. At the 4-hr. contact period the percentage survival of this organism, in these pH ranges, was 53.4 and 15.7 respectively.

6. An exposure of 2 hr. at room temperature to a pH of 11.01–11.50 or of 4 hr. to a pH of 10.51–11.0 was sufficient to produce a 100-per cent kill of the pathogens studied.

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American Water Works Association

TENTATIVE MANUAL

of

ZEOLITE TEST PROCEDURES

(Ion-Exchange Materials—Cation Exchangers Operating on the Sodium Cycle)

The American Water Works Association issues this text as a *Tentative Manual*. The Manual was prepared by a committee appointed by the Water Purification Division, which committee operated under the jurisdiction of the Committee on Water Works Practice. This is a Tentative Manual, *not* a set of specifications. It may be adopted as a *Standard* Manual after due time has elapsed. It is intended to be a general guide to persons having occasion to purchase zeolites to be used in water purification, but it is not intended to be a substitute for, nor to be superior to, competent engineering judgment based upon a complete understanding of special conditions.

Approved by the Board of Directors of the A.W.W.A., March 1943

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AMERICAN WATER WORKS ASSOCIATION

500 Fifth Avenue, New York 18, N.Y.

Foreword

The Water Purification Division of the American Water Works Association, acting in its field of routine activities, in 1932, organized a committee to develop specifications and methods of testing zeolites used in water treatment. The activities of this committee have, as have all other technical committees of the Association, been carried on under the jurisdiction of the Committee on Water Works Practice. The present document is a tentative manual of zeolite test procedures and does not contain a set of specifications for zeolites.

After the committee was assigned the preparation of this manual, it was apparent that something more than a few field tests or simple laboratory tests should be assembled. It was found that there was wide diversity in the tests made, used and proposed by various interested engineers, chemists, research workers and technicians.

The committee has assembled what, in its opinion, are the best and most suitable of these tests and offers them at this time as tentative procedures, subject to future corrections and changes.

Preliminary copies of the proposed procedures were sent to more than fifty interested persons, and constructive replies were received from more than thirty of them. At this time, therefore, this manual is in the nature of an umpire's decision. It is hoped that the publication of this report will lead to the development of better methods as the art progresses.

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TENTATIVE MANUAL OF ZEOLITE TEST PROCEDURES

(Ion-Exchange Materials—Cation Exchangers Operating on the Sodium Cycle)

Section 1—Scope

Sec. 1.1—Sodium Cycle Only

The term "zeolite," as hereinafter used in this "Manual of Zeolite Test Procedures," shall be taken to mean all granular cation-exchange materials operating on the sodium cycle, for removing hardness (Ca, Mg, etc., or iron (Fe) or manganese (Mn)) from a water supply, employing common salt (sodium chloride (NaCl)) as a regenerant. This manual deals with zeolites operating on the sodium cycle only.

Sec. 1.2—Anion Exchangers Excluded

Anion exchangers employing alkaline compounds such as hydroxides and carbonates as regenerants are not regarded as true zeolites and require separate test procedures which are not included in this manual.

Sec. 1.3—Cation-Exchange Materials

Cation-exchange materials may be classed as:

1.3.1. *Inorganic Materials (Siliceous):*

(1) Glauconite, or greensand (low capacity and high capacity)
(2) Precipitated synthetic gel (sometimes called wet process)
(3) Fused synthetic
(4) Clay group or "Bentonites"
(5) Miscellaneous

1.3.2 *Organic Materials:*

(1) Coal derivatives (made from coal, lignite, peat (humus-containing), etc.)
(2) Resins
(3) Miscellaneous (made from sugar, casein, wool, starch, wood, etc.)

Sec. 1.4—Object of Tests

The object of the tests herein described is to determine, as nearly as possible, the physical and chemical properties of zeolites by the use of laboratory methods, keeping in mind the necessity of correlating laboratory tests with actual performance of zeolites in service. It is recognized that laboratory tests do not indicate the quality of a zeolite over a period of time and under definite conditions of service as reliably as does experience.

Sec. 1.5—Limitations of Tests

The tests are only an indication of apparent results (comparative in nature), with actual operating results to be determined (as far as exchange capacity, in grains or kilograins, is concerned) by properly regulated acceptance tests to be determined in each case, preferably after the material has been properly conditioned or normalized—(1) at the beginning of operations and (2) at the end of a week or a month or any other suitable period.

Section 2—Suggested Definitions

Sec. 2.1—Zeolite

A zeolite is defined as any member of the family of hydrous silicates (aluminosilicates), such as the phillipsite, the montmorillonite or the natrolite groups (which are so called because many species intumesce before the blowpipe) and some clay minerals, ultramine, glauconite and chabazites. A smaller degree of ion exchange is found in feldspars and kaolinite. All of these minerals contain alkali or alkaline earth metals, and it is these metals which will ionize and exchange with ions in solutions. They are considered as analogous to the feldspars in chemical constitution. Since the original designation of zeolites, it has been found that organic materials as well as inorganic materials can be used to produce cation-exchange materials. There is no scientific justification for using the term "zeolite" to designate any of the cation-exchange materials in use today. Some thirty or forty years' use of the word "zeolite," however, has identified it so closely with base exchange and cation exchange in general, that the term is now generally accepted as covering both base-exchange and cation-exchange substances.

Furthermore, there seems to be no particular objection to extending the use of the word "zeolite" from the mineralogical field to the field of water treatment, because the cation-exchange reactions of these minerals in nature are similar to the reactions of the cation exchangers in water treatment processes.

Sec. 2.2—Cation

The cation is the positively charged particle, or ion, in an electrolyzed solution which travels to the cathode (a metallic ion and H^+) and, after being discharged, is evolved or deposited; hence it is any positive ion.

Sec. 2.3—Cation Exchange

Cation exchange is the property of exchanging a cation existing in a solid (zeolite) for another cation in solution. Exchange reactions are reversible and are used to a great extent in the field of water treatment.

Sec. 2.4—Anion

In an electrolyzed solution, the anion is the negatively charged particle, or ion, which travels to the anode; hence it is any negative ion.

Sec. 2.5—Ion Exchange

Ion exchange is a reversible interchange of ions between a liquid phase and a solid body (zeolite), which does not involve any visible change in solid structure.

Section 3—Suggested Terminology[1]

Sec. 3.1—Samples

The procedures outlined in *Standard Methods for the Examination of Water and Sewage*[2] [hereinafter called *Standard Methods;* all page numbers refer to the eighth edition] re: "Collection of Samples" (page 3) and "Sampling" (page 90) are suggested for sam-

[1] EDITORIAL NOTE: The following symbols to designate exchange capacity have been suggested. They are recorded herewith, but are not a part of the manual.

For convenience in referring to the capacity of cation-exchange materials, a terminology that combines the use of chemical symbols and the first letter of Latin words (so as to make them universally applicable) is suggested for use.

For sodium cation exchangers or sodium zeolites (abbreviated Na_2Z), the term "CaMgInV" should be used to represent capacity. "CaMgInV" stands for "CaMg in *valera,*" which means "CaMg in value," i.e. the amount of Ca and Mg which has entered into a unit volume of the zeolite in the Na_2Z

pling, preservation, etc., of any water to be tested according to the directions contained in this manual.

Sec. 3.2—Reports

The procedure outlined in *Standard Methods* re: "Expression of Chemical Results" (page 6) and "Reporting of Results" (page 53) is suggested for reporting quantity determinations on any water tested according to directions contained in this manual. (*See also* footnote 8, page 744.)

Sec. 3.3—Supplemental Reports

This form of report may be supplemented by methods of stating mineral analysis of water customarily accepted.

Section 4—Taking of Samples

Sec. 4.1—Representative Samples

The importance of obtaining a truly representative sample cannot be overemphasized. A sampling tube (Fig. 1) or a grain sampler [3] shall be employed in obtaining a representative sample, care being exercised to secure a full cross-section, so that the effects of automatic sizing or segregation are taken into account.

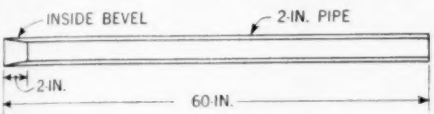

FIG. 1. Sampling Tube

Sec. 4.2—Samples for Shipping

If the material is shipped in containers, samples shall be taken from at least 5 per cent of them scattered throughout the entire shipment. If the material is shipped in bulk, samples shall be taken from top, half-way down and bottom from at least sixteen locations in the car. Samples from operating tanks or units shall total at least four samples per 100 sq.ft. of surface area, and in layers of lesser area a minimum of four samples shall be obtained.

These portions shall be mixed thoroughly into one composite sample of approximately 50 lb., then quartered or riffled to approximately 15 lb. of greensand or 9 lb. of synthetic or organic zeolite and immediately placed in an air-tight container.

Sec. 4.3—Air-Drying Not Recommended

Air-drying is not recommended, since zeolites, particularly the organic types, vary greatly in water content, even when in equilibrium with "air," and the density (apparent) is markedly influenced by the water content. When the tests for moisture, density and porosity have been determined by the procedures later described, it is believed that the assembled data will make it possible to compare zeolites on a convenient and practical basis.

Sec. 4.4—Draining for Sampling

To obtain, with the sampling tube (Fig. 1), a sample that will contain material from the entire depth of the zeolite layer, the water shall be drained from the entire zeolite layer down to the level of the top part of the sup-

cycle under a specified set of operating conditions.

The term "CationInV" stands for the capacity of the hydrogen zeolite (abbreviated H_2Z). In this case the Ca, Mg and Na cations are usually taken up.

[2] *Standard Methods for the Examination of Water and Sewage.* Am. Public Health Assn. & Am. Water Works Assn., New York (8th ed., 1936).

[3] Grain Sampler No. 12, ⅞ in. in diameter, as made by Eimer & Amend Co., is suggested. Either dry or wet samples can be obtained. This grain sampler consists of two revolving concentric tubes with suitable annular openings, the inner tube being provided with knobs for rotating purposes.

porting gravel layer. The sampling tube shall be driven into the drained layer.

Great care shall be exercised in re-wetting the zeolite to remove air pockets by opening valves slowly, to fill the unit from below.

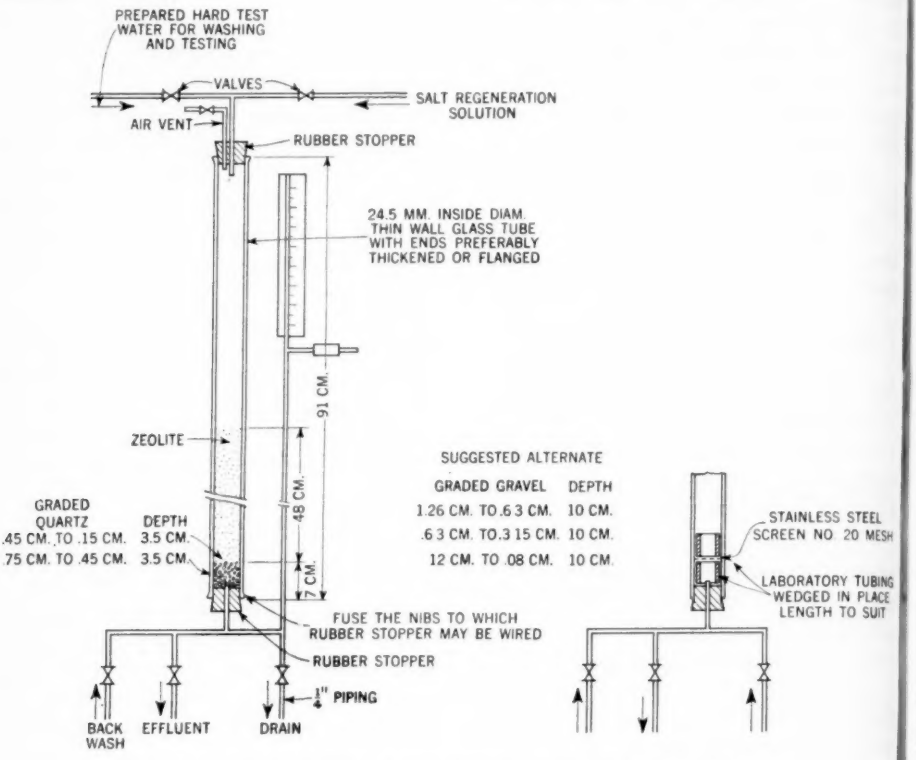
PREPARED HARD TEST WATER FOR WASHING AND TESTING
VALVES
SALT REGENERATION SOLUTION
AIR VENT
RUBBER STOPPER
24.5 MM. INSIDE DIAM. THIN WALL GLASS TUBE WITH ENDS PREFERABLY THICKENED OR FLANGED
91 CM.
ZEOLITE
48 CM.
7 CM.
GRADED QUARTZ
DEPTH
.45 CM. TO .15 CM. 3.5 CM.
.75 CM. TO .45 CM. 3.5 CM.
SUGGESTED ALTERNATE
GRADED GRAVEL DEPTH
1.26 CM. TO .6 3 CM. 10 CM.
.6 3 CM. TO .3 15 CM. 10 CM.
12 CM. TO .08 CM. 10 CM.
STAINLESS STEEL SCREEN NO. 20 MESH
LABORATORY TUBING WEDGED IN PLACE LENGTH TO SUIT
FUSE THE NIBS TO WHICH RUBBER STOPPER MAY BE WIRED
RUBBER STOPPER
1" PIPING
BACK WASH
EFFLUENT
DRAIN

FIG. 2A. Standard Tube Arrangement; showing direction of flow

Section 5—Amount of Zeolite for Tests

The approximate amounts of zeolite necessary for the various tests to be made according to these procedures are as follows:

Weight per cu.ft. backwashed...	500 grams
Sieve analysis.....	500 grams
Attrition loss.....	200 grams
Exchange value.....	1500 grams
Other determinations.....	500 grams
Total.....(Approx. 7 lb.)	3200 grams

Section 6—Tube Preparation and Calibration

Sec. 6.1—Type of Tube

The standard test tube unit shall be 24.5 mm. (± 10%) in internal diameter and 91 cm. long, of light-walled glass (or other suitable material). If the glass tube is flanged or thickened at the ends it will prove more sturdy.

Sec. 6.2—Calibration Procedure

A rubber stopper of proper size, containing a piece of glass tubing approximately ¼ in. in diameter, with the end flush to the small end of the stopper, shall be prepared. To the long end, a short piece of rubber tubing shall be attached. A "Hoffman"

screw clamp shall be used to regulate or to shut off flow. The rubber stopper shall be taped in place, for the weight of the layer of zeolite material is sufficient to loosen it. In mounting the tube, the bottom shall rest on a

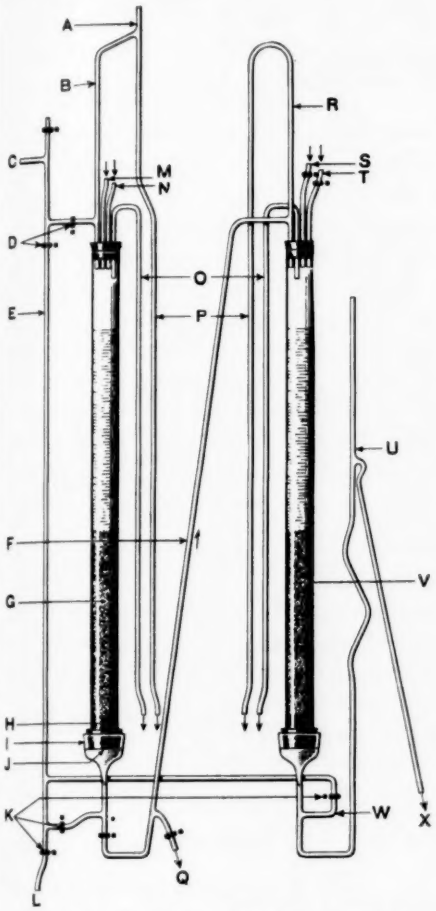

FIG. 2B. Alternate Tube Arrangement; showing direction of flow (*See* Key in adjoining column)

suitable support, and the tube shall be truly vertical, to prevent undesirable turning of the layer of zeolite.

On the bottom shall be placed 0.63 cm. graded quartz or suitable silica gravel (dirt and oil-free), round and clean, to a depth of about 3.5 cm. and, on top, 0.315 cm. graded material to a depth of 3.5 cm. All of this material in place shall be washed by upflow until it is clean. (An alternate supporting arrangement is shown in Fig. 2B.)

The tube shall be filled with water at 70°F. ± 10°F. (21°C. ± 6°C.). A height of 48 cm. above the quartz layer shall be measured with exactness, marking both top and bottom of the 48-cm. length; then the water shall be drained down to the top mark. Following this, the water between the top and bottom marks shall be drained into a graduate, measuring carefully the volume of water between the two marks. Water adhering to the wall of the tube shall be fully drained out.

Key for Fig. 2B

A—Suction Break
B—Safety Tube
C—Raw Water Inlet
D—Adjustable Clamps to Divert Water Flow to Top of Column
E—Tap Water (continuous flow)
F—Cation Exchange Effluent to Top of Anion-Exchange Column
G—Cation Exchanger
H—Gravel Layer
I—Büchner Funnel
J—70-Mesh Monel Metal Screen
K—Adjustable Clamps to Regulate Backwashes for Both Columns
L—Tap Water to Drain (continuous flow)
M—Rinse Water Inlet
N—Regenerant
O—Backwash Outlets
P—Safety Tube Overflows
Q—For Samples of Cation-Exchange Effluent
R—Safety Tube
S—Rinse Water
T—Regenerant
U—Adjustable Tube to Fix Water Level in Anion-Exchange Column
V—Anion Exchanger
W—Backwash Inlet
X—Distilled Water Outlet—Anion-Exchange Effluent

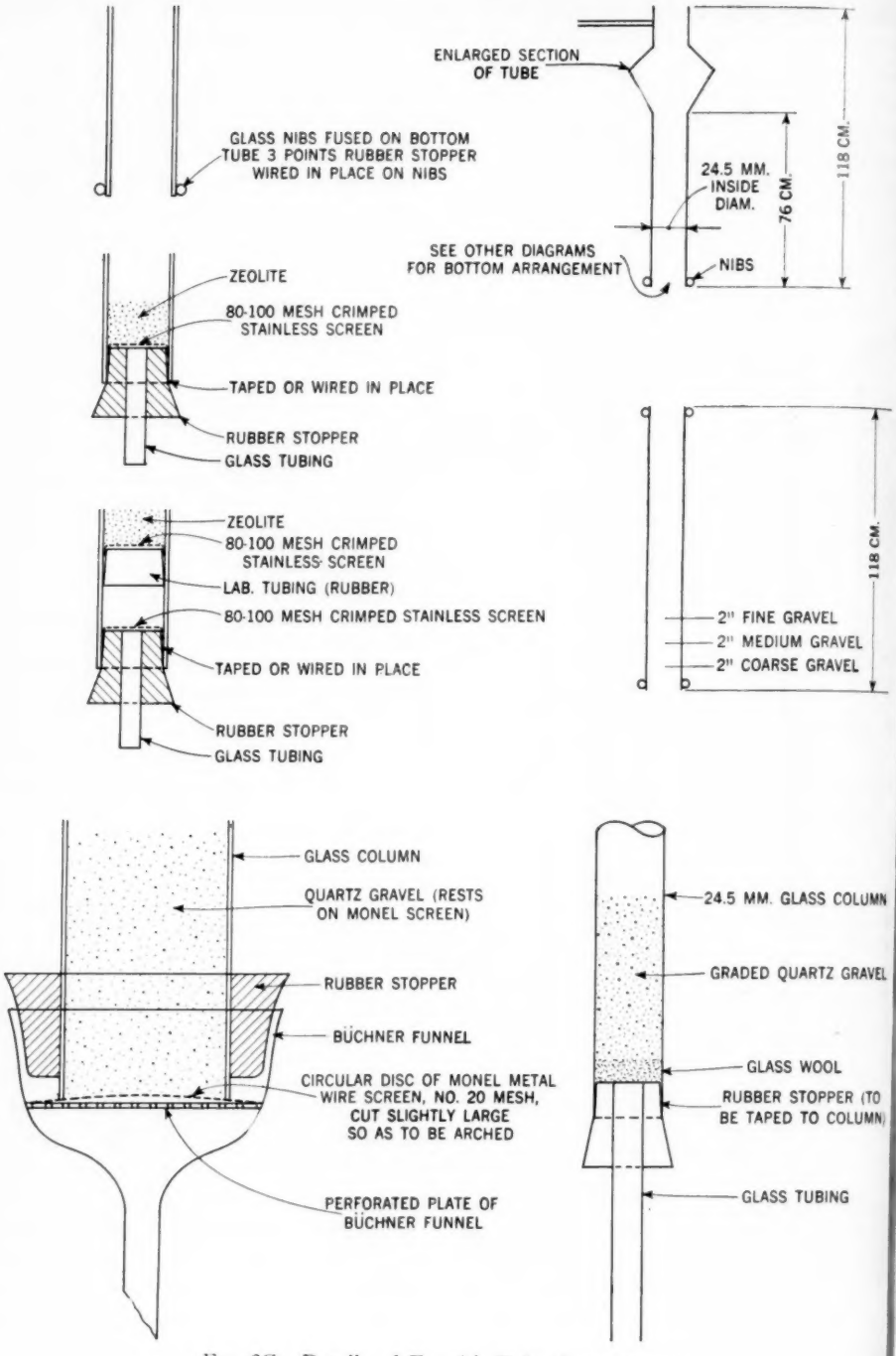

FIG. 2C. Details of FIG. 2A Tube Arrangements

Assuming that the measured volume equals 211 ml. and that 1 ml. = 0.0000353 cu.ft., then 211 ml. = 0.00745 cu.ft. occupied by 48 cm. in height. On this basis $\frac{0.00745}{1.666} = 0.00447$ sq.ft. = average area in the 48-cm. layer. The tube shall be permanently marked to show its area when the determination has been made.

Sec. 6.3—Calibration of Entire Tube for Organic Zeolites

For those zeolites in which the volume changes during the operation cycle, it may prove desirable to calibrate the entire tube by attaching a strip of graph paper,[4] ½ in. wide, along the axis of the tube. Calibration may be made by successive additions of water (10 ml.) from the burette, with volumes marked on the graph in convenient units. In such case, the "volume" factor shall be marked on the tube.

Sec. 6.4—Various Test Tube Diameters

Test tubes having a diameter other than that herein designated are being used, but it is felt that the diameter chosen will permit reasonably accurate and reproducible results with a minimum of sample (material) and test water requirements.

Section 7—Air-Drying

Sec. 7.1—Limitation

It is to be noted that under Sec. 4.3, air-drying is not recommended. Certain tests covered in this manual, however, state that air-drying of samples is a permissible procedure if reproducible results can be obtained. Therefore, a suitable air-drying procedure is given.

[4] 10 × 10 per ½ in., tenth lines heavy—equivalent to K & E No. 359-11.

Sec. 7.2—Air-Drying Procedure

To insure reproducible results when air-drying materials, the following procedure shall be used:

The sample shall be spread over the bottom of a suitable container to a depth of ½ in. Drying shall continue for 24 hr. and shall be facilitated by thorough mixing and spreading of the sample three times, at intervals of 8 hr., for the organic materials. Twice the time and number of stirrings shall be employed for inorganic materials. On completion of the sieve analysis, the moisture content of the sample shall be determined. (*See* Supplementary Notes, p. 750.)

Sec. 7.3—Moisture and Density

The total moisture of this sample shall be determined as in Sec. 11 and the density of the dried material determined as in Sec. 10. The density of the sample "as is" should be determined in a similar manner, and the "wet-down" density as indicated in Sec. 20.3.

Section 8—Oven-Drying

Sec. 8.1—Procedure

When oven-drying is specified, the zeolite sample shall be dried to a constant weight in an oven capable of maintaining a temperature of 105° to 110°C.[5] It shall then be cooled in a desiccator before weighing. Zeolite shall be regenerated to its sodium form and rinsed before drying.

[5] Construction details of an oven satisfactory for this procedure are given in an article entitled "A Temperature and Humidity-Controlled Dryer for a Chemical Engineering Laboratory," by ROBERT M. SCHAFFNER & JAMES COULL of the University of Pittsburgh (Ind. Eng. Chem.—Anal. Ed., **14**: 590 (1942)).

Sec. 8.2—No Re-Use in Tests for Attrition or Aggressivity

Synthetic, carbonaceous or resinous zeolites that have been oven-dried according to this method cannot be used for attrition or aggressivity tests, because drying at 105° to 110°C. causes further decrepitation and the zeolite does not (when cooled off) possess the property of readsorbing proper amounts of water of hydration. Resinous zeolites can be brought back to original exchange value, but may crumble, thus affecting grain size.

Section 9—Jarring or Shaking

Sec. 9.1—Mechanical Jarring and Shaking

To assure the maximum of uniformity in results when jarring is specified, jarring shall consist of vibrating the sample and container for 1 min. on a mechanical shaker at 150 taps per min., and shaking shall be for a 3-min. period. (Organic materials require a longer shaking period, but no precise time, which will be correct for all, can be given.) A 5-per cent speed tolerance is allowable.

The "Ro-Tap Testing Sieve Shaker," manufactured by W. S. Tyler Co. of Cleveland, Ohio, and the portable "Cenco-Meinzer Sieve Shaker," manufactured by the Central Scientific Co. of Chicago, are acceptable types of mechanical equipment.

Sec. 9.2—Manual Jarring

The container can be jarred by hand until there is no appreciable settling of the zeolite, then more zeolite added to fill the container to total capacity, with additional jarring to be sure that the measuring container is full.

Sec. 9.3—Manual Shaking

In manual shaking, the nest of sieves containing the sample shall be rocked back and forth over a piece of wood so that the bottom of the pan is about 1 in. above the table top. The rocking shall be at the rate of 150 bumps per minute (75 on each side), bumping the entire nest against a wood table for 5 min. Sieves shall be bumped lightly and not bounced. Heavy bouncing will produce erratic results.

Section 10—Weight of Dry Zeolite per Cubic Foot (Density Data)

Sec. 10.1—Apparatus

The apparatus required consists of: (1) one 1000-ml. graduated glass cylinder; (2) a drying oven capable of maintaining a temperature of 105° to 110°C.; and (3) a balance, sensitive to 0.5 g. in 1000 g.

Sec. 10.2—Procedure

10.2.1. *Greensand Zeolite:* The graduated cylinder shall be weighed. Oven-dried greensand zeolite shall be poured into the graduated cylinder to a little over the 1000-ml. mark, shall be jarred (*see* procedure under Sec. 9.2), and operations shall be finished with exactly 1000 ml. The cylinder and the zeolite shall be weighed quickly. The difference in weight of the cylinder and the zeolite and the empty cylinder is the weight of dry zeolite, in grams per 1000 ml. Then:

$$\text{Dry wt. per cu.ft. (in lb.)} = \text{Wt. (in g.) of 1000 ml.} \times \left(\frac{3.785 \times 7.48}{453.6}\right)$$

$$= \text{Wt. (in g.)} \times 0.0624$$

10.2.2. *Other Types of Zeolite:* When resinous and carbonaceous zeolites are shipped dry (unwetted), an additional wetted weight per cubic foot of material shall be determined. To make this determination, the material

shall first be immersed in water, i.e., thoroughly wetted. This wetting shall be such as to insure complete swelling of the particles. The material, after wetting, shall be drained to remove "free" water before it is placed in the test tube.

To make the results of this test reproducible it has been suggested that a "B&D" (backwashed and drained) volume be used instead of a jarred volume.

The moisture content of all zeolite to be tested shall be determined on duplicate average samples, by methods described in Sec. 11. This moisture content shall be recorded and reported.

Section 11—Total Moisture in Zeolite as Received

Sec. 11.1—Apparatus

The apparatus required consists of: (1) one 2-in. diameter standard weighing bottle (stoppered); (2) a drying oven capable of maintaining a temperature of from 105° to 110°C.; and (3) an analytical balance and dessicator.

Sec. 11.2—Procedure

The weight of the weighing bottle and stopper shall be determined. About 3 g. of zeolite shall then be placed quickly in the weighing bottle and the bottle sealed immediately with the stopper. The bottle and sample shall be weighed. Then, the stopper shall be removed and the bottle placed in the oven, maintained at 105° to 110°C. It shall then be dried for 12 hr. or to constant weight. For calculation of moisture, the following equation may be used:

$$\frac{\text{Loss in wt.}}{\text{Wt. of sample}} \times 100 = \% \text{ moisture as received}$$

NOTE—Synthetic (inorganic) zeolite loses its water of hydration at 105° to 110°C., and the moisture is not returned on atmospheric cooling; thus, after this test, the sample should be thrown away, as its exchange value is affected. Resinous zeolite can be brought back to exchange capacity but may crumble.

Section 12—Moisture in Air-Dried Sample

Moisture in the air-dried sample is to be determined by the total moisture method (Sec. 11).

Section 13—Weight per Cubic Foot of Zeolite as Received

Sec. 13.1—Apparatus

The apparatus required consists of: (1) small platform scales, weighing in pounds and ounces; and (2) a 1-cu.ft. box (preferably with rigid sides), wood or steel. This box shall be made to fit a "Ro-Tap," or equal, shaking machine so that reproducible results can be obtained.

Sec. 13.2—Procedure

The box shall be weighed to the nearest ounce, then quickly filled to overflowing with zeolite, just as it is received in the sample shipping containers. The box shall then be jarred (*see* procedure under Sec. 9) and the excess zeolite stricken off the top of the box with a suitable straight edge. The box and the zeolite shall then be weighed to the nearest ounce. The total weight minus the weight of the box gives the weight of the zeolite, per cubic foot, as received.

NOTE—The box can be jarred by hand until there is no appreciable settling of the zeolite, and then additional zeolite added to fill total capacity, with additional jarring to be sure the measuring container is full.

Section 14—Weight per Cubic Foot of Saturated Settled Zeolite After Backwashing

Sec. 14.1—Apparatus

The apparatus required consists of: (1) one softener unit (glass tube) as shown in Figs. 2A, B and C; and (2) a balance sensitive to 0.5 g. in 100 g.

Sec. 14.2—Procedure

A sufficient amount of the zeolite sample to make a layer approximately 48 cm. deep shall be weighed accurately. About 48 cm. of water shall be placed in the tube and the zeolite poured slowly into the water. If the zeolite tends to swell, it shall be checked at intervals until the swelling has ceased. The zeolite shall then be backwashed in an upward direction for 20 min. with clear tap water at a rate sufficient to give 50 per cent expansion of the zeolite layer, uniformly maintained for 15 min.

The backwash shall be decreased slowly for the last 2 min. and, when stopped, the effluent valve shall be opened so that water is drained off at the average rate of 12 cm. per min. The operation shall be stopped with 0.63 cm. water above the top of the sand, and the volume (in cubic feet) of the saturated layer of zeolite measured. (Care should be taken to avoid shaking or tapping the tube when making volume measurements and to prevent quiescent settling between backwashing and draining.) On this basis:

$$\frac{\text{Wt. of zeolite (in lb.)}}{\text{Vol. of satd. zeolite (cu.ft.)}} = \text{Wt. of zeolite as received (in lb./cu.ft.) in position in softener}$$

and:

$$\frac{\text{Wt. of zeolite } (100 - \% \text{ moisture})}{100 \times \text{cu.ft. of satd. zeolite}} = \text{Wt. of zeolite per cu.ft. (dry basis)}$$

Three separate tests should be conducted and the average result reported.

Section 15—Sieve Analysis of Zeolites

Sec. 15.1—Apparatus

The apparatus required consists of: (1) sieves; (2) one sieve pan; (3) one sieve cover; and (4) a balance or scale sensitive to 0.1 g. in 300 g.

The sieves are to be 8 in. in diameter, square mesh, having ASA Standard sieve openings or the corresponding Tyler standard sieve openings. Sieves shall meet the requirements of the ASA specifications document Z23.1–1939, as follows:

Standard Specifications for Sieves for Testing Purposes

Sieve No.	Openings, in Millimeters ASA Std.	Tyler
8	2.38	2.36
10	2.00	—
10	—	1.65
16	1.19	—
20	0.84	0.833
30	0.59	0.589
40	0.42	0.417
50	0.297	0.295
60	0.250	—
65	—	0.208

Sec. 15.2—Procedure

A sample of air-dried zeolite of a weight as follows, shall be taken:

For materials bulking approx:
25 to 40 lb. per cu. ft.— 50 grams
40 to 65 " " " "—100 grams
65 to 95 " " " "—200 grams

In the sieve analysis of synthetic zeolites extreme care must be exercised in removing the zeolite from the sieves for weighing, as the material has a tendency to bounce and thereby be lost. This causes low results and makes it impossible to check within the tolerance required. It is recom-

mended that the sieves be cleaned and all weighing be made over a black surface.

For materials which swell when wetted, similarly conducted tests shall be made on oven-dried material, a fully swollen sample, and a sample "as received," if possible.

For synthetic or coarse-grained zeolites, sieves Nos. 8, 10, 16, 20, 30, 40 and 50 shall be used.

For organic zeolites and greensand, sieves Nos. 10, 16, 20, 40, 50 and 60 shall be used.

The material shall be shaken for 3 min. in a mechanical shaker or for 5 min. manually (*see* Sec. 9.3).

Sec. 15.3—Reporting Results

The sieve analysis shall be reported in percentage by weight to the nearest 0.1 per cent retained on the various sieves, and the result preferably plotted on logarithmic paper. Following is an example of a proper form of report:

	Per Cent
Retained on No. 8 sieve	—
Passing No. 8 and retained on No. 10	—
" No. 10 " " " No. 16	—
" No. 16 " " " No. 20	—
" No. 20 " " " No. 30	—
" No. 30 " " " No. 40	—
" No. 40 " " " No. 50	—
" No. 50 " " " No. 60	—
" No. 60 " " " No. 65	—
" No. 65 " " " pan	—
Total	—

(Specify sieve used—ASA Std. or Tyler)

If the percentages do not total 100, correction shall be made on the largest quantity retained on any sieve. If the sum of the weight retained on each sieve and that which passes the smallest size sieve is less than 99 or more than 101 per cent, however, the test shall be discarded and another test made.

NOTE—Different screen fractions will contain a different percentage of moisture due to their difference in grain sizes and the lack of time to approach a uniform moisture condition of the zeolite. After the quick air-drying operation, the sample should preferably be held in a sealed jar overnight so that the moisture content may become uniform throughout.

Section 16—Determining Attrition Losses of Zeolites

Accelerated tests thus far devised cannot be relied upon to furnish completely reliable data concerning the probable life and operating characteristics of a zeolite when placed in actual service. The tests have some value, however, in supplying comparative data which may be used as a guide. Suggested forms of tests have been prepared for the following materials: (1) greensand; (2) synthetic gels, fused synthetic, bentonites, miscellaneous; (3) carbonaceous zeolites and resinous zeolites.

Sec. 16.1—Scheme A—Greensand Zeolites

16.1.1. *Apparatus:* The apparatus required consists of: (1) one 4-oz. rubber-stoppered oil-sample or other bottle (about 1½ in. in diameter by 6½ in. overall); (2) one rotating shaking wheel (axis horizontal, to rotate at 17 rpm., with provision for connecting the bottle 1 in. from center of shaft (Fig. 3)); (3) one calibrated 1-liter

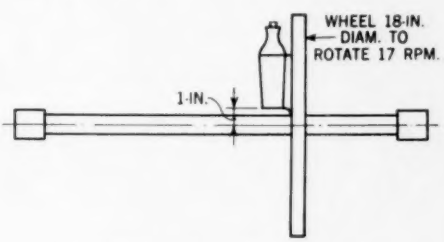

FIG. 3. Rotating Shaker

volumetric flask; and (4) a Jackson turbidimeter.

16.1.2. *Sampling:* Sampling shall follow the method of Sec. 4. If taken from a zeolite unit that has been used or is in actual use, samples shall be taken after regeneration.

16.1.3. *Procedure:* 50 g. of air-dried regenerated zeolite shall be placed in the container, which shall then be filled with distilled water of approximately 70°F. temperature, and stoppered. The bottle shall be connected to the mixing wheel and revolved 2 hr. at 17 rpm. The bottle shall then be removed and allowed to settle 15 sec., after which the supernatant liquid shall be poured into the 1-liter volumetric flask. The zeolite shall then be washed until the washings are clear.

After the washings have been collected in the volumetric flask, sufficient distilled water shall be added to fill the flask to the 1-liter mark, and these shall be mixed. The turbidity of the sample shall then be determined with the Jackson candle turbidimeter, to give a measure of the resistance to attrition in parts per million turbidity. Attrition value shall then be obtained as follows:

$$\text{Attrition value} = \frac{10{,}000}{\text{Turbidity (in ppm.)}}$$

Sec. 16.2—Scheme B—Synthetic Zeolites

16.2.1. *Apparatus:* The apparatus required consists of: (1) a balance or scale (sensitive to 1 mg.); (2) a shaker ("Tyler Ro-Tap"); (3) one 5-oz. squat-form screw-cap jar; and (4) sieves.

16.2.2. *Procedure:* From the air-dried sample that has not been previously shaken, a portion passing the No. 14 sieve and retained on the No. 20 sieve shall be sieved out. From this portion 20 g. shall be weighed out accurately (on the dry basis). This material shall then be placed in the screw-cap jar and 75 ml. of distilled water at room temperature added. The jar shall then be capped and placed flat in the shaker pan and packed tightly with cloth or wadded paper. The lid shall then be placed on and the assembly clamped in the shaker. Shaking shall continue for 2 hr.

After shaking, the jar shall be removed and allowed to settle 15 sec. The liquid shall then be poured off into a 1-liter volumetric flask. To the zeolite in the jar about 75 ml. of water shall be added, the jar capped, turned over, the cap removed and the water poured into the flask. This procedure shall be repeated at least six times, after which the washings in the flask shall be made up to 1 liter, mixed and allowed to stand 5 min. Then 500 ml. shall be poured off.

Turbidity shall be determined by comparison with standards or by the Jackson candle turbidimeter. The greater the turbidity, the lower is the resistance to attrition.

Sec. 16.3—Scheme C—Carbonaceous and Resinous Zeolites

An alternate method which has been designed for use with carbonaceous zeolites has been published.[6] Briefly it is as follows:

16.3.1. *Apparatus:* The apparatus required consists of: (1) a reciprocating machine having a moving frame in which the attrition bottles are clamped and agitated rapidly back and forth horizontally, along their axis, and in

[6] Broderick, S. J. & Hertzog, E. S. Accelerated Tests for Determination of Attrition Loss of Carbonaceous Zeolites. Jour. A.W.W.A., **34**: 94 (1942).

which the moving frame is driven by a wheel rotating at about 162 rpm., with a $3\frac{3}{32}$-in. stroke, and connecting rod (Fig. 4); (2) several wide-mouthed screw-capped bottles, 2 in. in diameter by $4\frac{1}{4}$ in. high, with water-tight screw-caps; (3) a Jackson turbidimeter; (4) two 6-in. diameter Tyler sieves, 28- and 35-mesh; (5) four 3-in. diameter Tyler sieves, 42-, 48-, 100- and 200-mesh; and (6) beakers, funnels, a filter rack and an analytical balance.

16.3.2. *Sampling:* The sample to be tested shall always be a regenerated zeolite. The material shall be hand-screened on 28- and 35-mesh. The 28- to 35-mesh fraction shall be the part used as the attrition sample. Great care shall be exercised to see that all minus 35-mesh material is completely removed. Material sticking in the 35-mesh sieve shall be discarded. The samples shall be air-dried at room temperature.

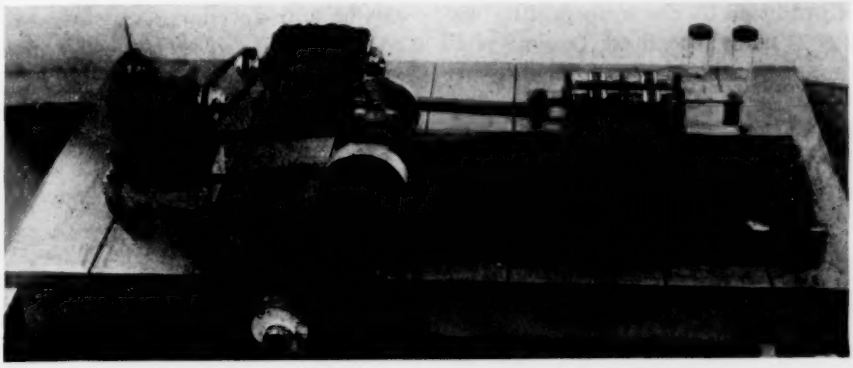

FIG. 4. Reciprocating Machine for Attrition Testing

16.3.3. *Procedure:* A 5-g. sample of 28- to 35-mesh material shall be weighed out and placed in a screw-capped bottle containing 50 ml. of distilled water. The cap shall then be tightly replaced. A duplicate sample shall be weighed out and treated in exactly the same manner except that the first sample shall be agitated for 4 hr. on the machine, while the second sample shall not be agitated. The second sample shall serve as a blank to correct any degradation due to moistening, drying or screen abrasion. It shall also be used in corrections for incomplete removal of fines. After this, each sample shall be wet-screened by washing onto a nest of 100- and 200-mesh 3-in. diameter sieves, these sieves being placed in a large funnel and the turbid liquid and fines passing 200-mesh being caught in a small beaker. The 100-mesh sieve will retain at least 95 per cent of the sample. This material need be washed only enough to insure that all minus 200-mesh material passes the 100-mesh sieve. It is not necessary to wash all minus 100-mesh material through the 100-mesh sieve because the material is combined, air-dried and screened again.

Next, the upper sieve containing most of the sample shall be removed and the small quantity of plus 200-mesh material washed on the 200-mesh sieve with a fine jet of water. This assures accurate wet-screening on 200-mesh. Then the material on the two sieves shall be combined and

air-dried at room temperature. The total amount of turbid water shall be considerably less than 200 ml. and shall then be diluted to 200 ml. in a volumetric flask and turbidity determined on the Jackson turbidimeter.

The air-dried samples of plus 200-mesh material shall be placed in a nest of 3-in. diameter sieves, 42-, 48- and 100-mesh. The sieves shall be given a rotary motion, followed by several light blows on the side with the open hand. This sequence shall be repeated constantly during a 5-min. period. The sieves shall not be pounded violently on a desk or table top, because the abrasion resulting may be greater than that produced by the reciprocating machine. Finally, the sized fractions shall be weighed and blank corrections applied.

16.3.2. *Reporting Results:* Data from an average sample shall be reported as follows:

Mesh	*4-Hr. Attrition, g.*	*Blank Attrition, g.*	*Net Weight, g.*	*Surface Ratio*	*Relative Surface*
− 42 + 48	0.0112	0.0048	0.0064	1.	64
− 48 + 100	0.0172	0.0058	0.0114	1.391	159
− 100 + 200	0.0060	0.0018	0.0042	2.786	117
					340
− 200 turbidity	190 ppm.	Clear	190 ppm.		

The attrition value 340 measures roughly the new surface formed in the − 42 + 200 size range and is more accurate than using the weights alone. The attrition value and turbidity readings shall both be used in studying the attrition loss of carbonaceous zeolites.

Section 17—Resistance of Zeolites to Aggressive Attack

Tests used and proposed by technicians are so far removed from normal water softening plant operations that results may not only be meaningless, but quite misleading, and may have no particular significance in relation to the durability of the zeolite in different types of water.

For example, some waters are extremely low in silica; therefore the synthetic zeolites will not stand up, but will lose silica by dispersion. Distilled water in connection with such zeolites under standardized conditions will show pick-up of silica from the zeolite. Other destructive factors occurring in water are, or may be, iron, manganese, variation of pH and high free CO_2. Therefore, tests should be devised to measure these destructive forces, but further laboratory work will be necessary before adequate tests can be announced.

The validity of the procedures hereinafter described is not yet fully established.

To record definite procedures that can be used for comparison purposes only, five methods are suggested: (1) for low pH conditions; (2) for high pH conditions; (3) for conditions encountering excess of concentrated brine; (4) for conditions encountering deficiency of silica; and (5) for conditions contributing to the breakdown of organic zeolites.

Sec. 17.1—Method A—Low pH Conditions

17.1.1. *Solutions:* (1) A buffered solution, with a pH of 4.0, shall be prepared by taking 50 ml. *M*/5 potassium acid phthalate ($KHC_8H_4O_4$) and 0.40 ml. *M*/5 sodium hydroxide

(NaOH), and adding boiled and cooled re-distilled water to make 200 ml. (2) A 5-per cent solution of cp. sodium chloride (NaCl) (for regenerating purposes). (*See* Supplementary Notes, page 750.)

17.1.2. *Procedure:* After thorough regeneration of the sample (using Solution 2) and rinsing, the material shall be air-dried and about 15 g. shall be screened out to 30–40 mesh (U.S. Bureau of Standards). Moisture content shall then be determined (Sec. 11).

Duplicate samples of this air-dried material shall be weighed out, each sample weighing 1.0 g. net (calculated on dry basis after making allowance for moisture content). Each sample shall be placed in a 4-oz. rubber-stoppered oil-sample bottle (about 120 ml.) and filled with Solution 1. The bottles shall then be stoppered tightly and mounted on a rotating wheel, with the bottom of the bottles about 1 in. from the center. Rotation shall be for 2 hr. at 17 rpm., with the room at from 20° to 25°C. The supernatant liquid shall then be decanted and the residual material thoroughly rinsed with distilled water, being careful not to lose any of the zeolite grains. The washed zeolite shall be transferred to a weighing bottle and shall be oven-dried and reweighed after the cooling. Finally, the percentage loss of weight on the 1.0-g. samples shall be calculated as percentage weight loss due to aggressive attack under the test conditions.

Sec. 17.2—Method B—High pH Conditions

17.2.1. *Solutions:* (1) A buffered solution, with a pH of 9.0, shall be prepared by taking 50 ml. *M*/5 boric acid (H_3BO_3), 50 ml. *M*/5 potassium chloride (KCl) and 21.30 ml. *M*/5 sodium hydroxide (NaOH) made up to 200 ml. and adding distilled water as described in Method A (Sec. 17.1.1). (2) A 5-per cent solution of cp. sodium chloride (NaCl) (for regenerating purposes).

17.2.2. *Procedure:* The procedure described under Method A (Sec. 17.1.2) shall be followed.

Sec. 17.3—Method C—Conditions Encountering Excess of Concentrated Brine

17.3.1. *Solutions:* (1) Boiled and cooled redistilled water. (2) A 25-per cent solution of cp. sodium chloride (NaCl) (for regenerating purposes).

17.3.2. *Procedure:* The zeolite shall be regenerated with Solution 2, after which the procedure described under Scheme A (Sec. 16.1.3) subsequent to the end of the rotation period shall be followed.

Sec. 17.4—Method D—Conditions Encountering Deficiency of Silica

17.4.1. *Solution:* (1) Boiled and cooled redistilled water. (2) A 5-per cent solution of cp. sodium chloride (NaCl) (for regenerating purposes).

17.4.2. *Procedure:* The procedure described under Method A (Sec. 17.1.2) shall be followed to the end of the rotation period, except that the sample shall be placed in Solution 1. Pyrex glassware shall be used. The supernatant liquid and the rinsings of distilled water shall be decanted and saved. The silica in the liquid shall be determined and the loss from that of the original sample calculated.

Sec. 17.5—Method E—Conditions Contributing to Breakdown of Organic Zeolites

17.5.1. *Solutions:* Buffered solutions shall be prepared in a manner

similar to those shown in Methods A and B (Secs. 17.1.1 and 17.2.1), but with varying amounts of $M/5$ sodium hydroxide (NaOH) to give a range of pH values.

17.5.2. *Procedure:* The zeolite samples shall be tested in these solutions, employing the procedure described under Method D (Sec. 17.4.2), except that the supernatants and rinsings shall be analyzed for dissolved organic matter, employing the oxygen consumed tests as described in *Standard Methods* (page 51). The loss shall be related to the total organic matter as run on a sample of original material.

Section 18—Determining the Exchange Values of Zeolites

This method of test comprises the determination of the operating exchange or capacity value (sodium cycle) of cation-exchanging zeolites and not the total exchange, because, in practice, it is not customary to operate zeolite softeners until they are completely exhausted, but to operate only to a definite hardness end-point.

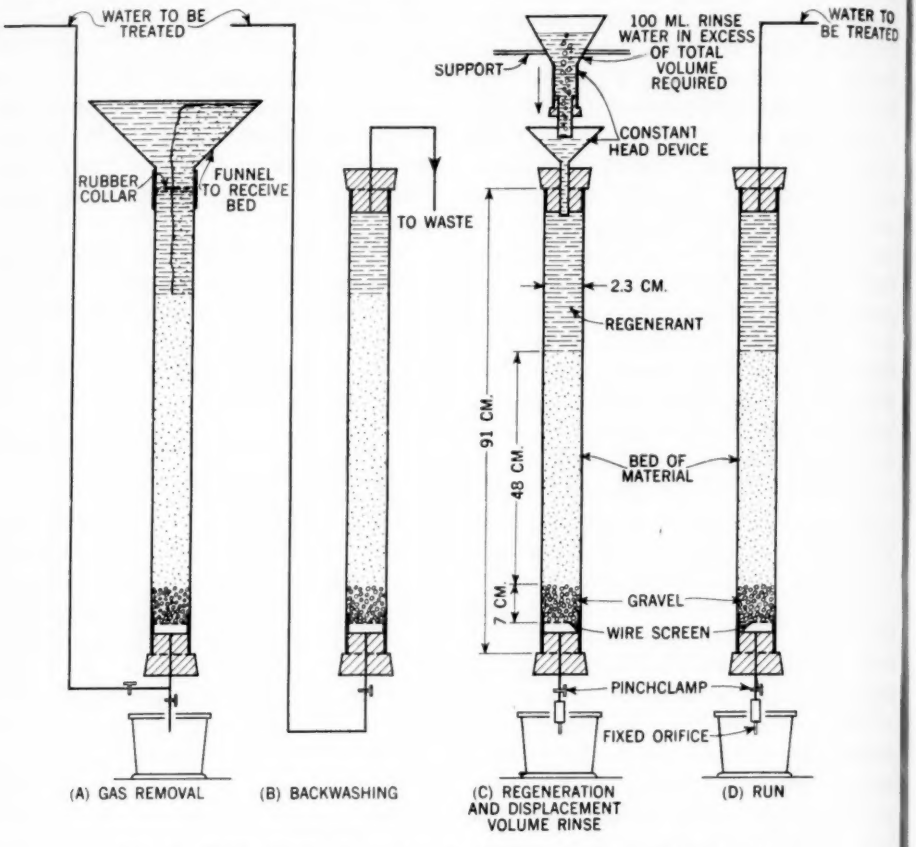

FIG. 5. Tube Arrangement for Exchange Capacity Determinations

Sec. 18.1—Apparatus

18.1.1. *Test Unit:* A standard calibrated test unit (Figs. 2, 5, 6) shall be used. Attachments to the tube shall

be made so that the softener tube can be used for upward or downward flow. A means of regulating the rate of flow of the backwash and effluent shall be provided.

18.1.2. *Receivers:* Any calibrated container may be used as a receiver.

18.1.3. *Test Bottle:* A 100-ml. rubber-stoppered bottle shall be used.

Sec. 18.2—Synthetic Test Water

A supply of synthetic test water (25 gal.) shall be made up as follows:

18.2.1. *Solution 1* (for synthetic, resinous and carbonaceous zeolites):

400 ppm. Total Hardness (as $CaCO_3$)
$CaCl_2$ (anh.) . . . . 1.115 g./gal.,[7] or 0.296 g./l.[7]
$MgSO_4 \cdot 7H_2O$ . . . . 1.251 g./gal., or 0.332 g./l.

18.2.2. *Solution 2* (for greensand zeolites):

170 ppm. Total Hardness (as $CaCO_3$)
$CaCl_2$ (anh.) . . . . . 0.473 g./gal., or 0.126 g./l.
$MgSO_4 \cdot 7H_2O$ . . . . . 0.530 g./gal., or 0.141 g./l.

18.2.3. *Solution 3* (for high capacity zeolites):

300 ppm. Total Hardness (as $CaCO_3$)
$CaCl_2$ (anh.) . . . . . 0.835 g./gal., or 0.199 g./l.
$MgSO_4 \cdot 7H_2O$ . . . . . 0.936 g./gal., or 0.248 g./l.

Sec. 18.3—Natural Water

When the tests are made on a natural water, its hardness and composition shall be accurately determined.

[7] In these abbreviations, the "g." stands for gram, *not* grain, which is not abbreviated.

Sec. 18.4—Salt Solution

18.4.1. *Quantity:* 1 gal. of 5-per cent cp. salt solution shall be used. The following table summarizes the volumes of 0.855 *N* sodium chloride (5 per cent) used for sodium zeolites of different types for this standard laboratory test. The quantity may be varied, however, for particular tests.

Salt—lb./1000 grains removed	*Zeolite Material*	*Quantity of Salt: grains/cu.ft.*	*lb./cu.ft.*	*mE/l**	*Vol. 0.855 N Sodium Chloride (5 per cent) required for 200-ml. unit*
0.45	Greensand	2,800	1.26	0.347	81
0.40	High Capac. Greensand	5,500	2.19	0.600	139
0.40	Synthetic	11,700	4.67	1.27	286
0.40	Carbonaceous	7,000	2.80	0.77	179
0.40	Resinous	12,000	4.80	1.32	308

* *See* footnote 8, p. 744.

18.4.2. *Quality:* The salt (NaCl) should not contain more than 2 per cent Ca and Mg salts, expressed as sodium chloride; and the analysis of the salt used shall be stated.

18.4.3. *Strength of Solution:* Salt solution shall be made from tap water to a strength of 0.855 *N* (5 per cent) by weight of salt (NaCl).

18.4.4. *Temperature:* The room temperature during zeolite exchange value tests shall be 70°F. ± 10°F. (21° ± 6°C.).

18.4.5. *pH:* Hard water (tap) shall be used for making the brine. The pH value of the brine shall be above 7.0, but not more than 8.3. The pH value shall be recorded.

Sec. 18.5—Soap Solution

18.5.1. *Standard Soap Solution:* Standard soap solution made according to *Standard Methods* (page 59) shall be used in all determinations where an issue exists concerning the acceptance of zeolites or their conformance to specifications.

18.5.2. *B&B Soap Solution:* Soap solution made according to Boutron-Boudet (*Standard Methods* Zeolite Softener Field Test, page 103) may be used in field or routine testing of performance of zeolites, but it shall not be used as a basis of acceptance or rejection of zeolites.

Sec. 18.6—Volume

An amount of the sample in excess of that apparently required to give a 48-cm. zeolite layer shall be weighed out. The procedure of Sec. 14.2 shall then be followed to place the sample in the water up to the 48-cm. mark. The unused portion shall be weighed and (by difference) the weight in the tube recorded. Materials that swell shall be permitted to stand until swelling has ceased. The procedure of Sec. 14.2 shall then be followed to determine the volume. Tests shall be repeated until consistent results are obtained; and values shall be recorded.

It will be permissible to add or subtract material to adjust the zeolite volume at exactly 48 cm. when backwashed and drained. The gross weight and net dry weight of the 48-cm. bed shall be calculated in terms of the relative volumes.

Sec. 18.7—Preliminary Treatment

Many materials (zeolite minerals) are placed on the market in an alkaline condition so that it is necessary to remove this free alkali by repeated backwashings and downflow operations before starting the test. Excessive amounts of alkali affect the exchange capacity and therefore give false results. To determine when the free alkali has been removed, a 15-min. soaking test with the water to be softened shall be made. In this test, the hydroxide alkalinity of the water standing in the zeolite layer during the soaking period, when drained off, shall not exceed 3 ppm. Following this thorough removal of free alkali, the zeolite shall be given two or three successive regenerations with salt (NaCl) to insure complete removal of calcium and magnesium salts. The regular test runs may then be started, but it will be necessary to discard the first few runs, which will probably be abnormally long. The result of these initial runs shall be recorded, but shall not be considered as representative until fairly constant results are obtained on several runs under a given set of conditions.

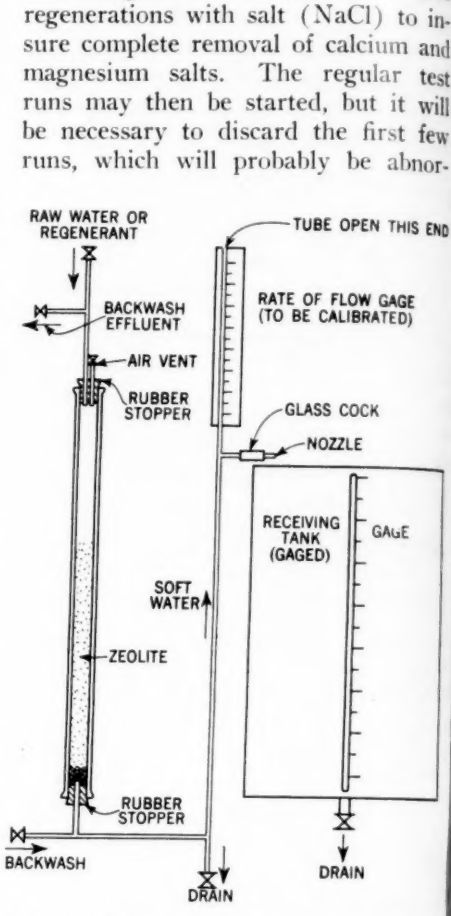

FIG. 6. Calibrated Tube Arrangement for Exchange Capacity Determinations

Sec. 18.8—Backwashing Operation

18.8.1. *Arrangement:* The rubber connections for backwashing shall be

as shown in Fig. 6. At the end of each softening run, the zeolite layer shall be backwashed thoroughly to cleanse and loosen it. The water to be treated shall be used to backwash. The flow rate during backwashing shall be sufficient to expand the zeolite approximately 50 per cent, and the period of washing shall be long enough to remove all dirt collected in the tube or in the layer during the softening run. The backwash time shall usually be about 5 to 10 min.; the time shall be recorded.

18.8.2. *Gas Removal:* If a considerable amount of air or gas collects in the layer during the run, it will be necessary to employ special means to remove such entrained gases before proceeding with the normal backwashing operation. The zeolite shall be backwashed into a large funnel, connected to the top of the tube with wide rubber tubing as shown in Fig. 5(A). Then the layer shall be allowed to return to the tube by draining all of the material from the funnel back into the tube, after which the backwashing procedure described in Sec. 18.8.1. shall be followed.

Sec. 18.9—Regeneration Operation

18.9.1. *Brine Introduction and Displacement Volume Rinse:* The tube connections and constant head device for regeneration and rinse are shown in Fig. 5(C). After backwashing, the tube shall be drained until the water level is about 1 cm. above the top of the layer. The tube shall be filled with regenerant to the point where it is just possible to fit the narrow-stem funnel into the top of the tube with a rubber stopper. The remainder of the regenerant shall then be poured into the funnel.

The fixed orifice or capillary shall be placed at the bottom of the tube and the clamp on the outlet opened. The bottle containing the rinse water shall then be placed in position. Regenerant and water shall be allowed to flow until the regenerant and displacement water have passed through the zeolite.

It is advantageous to have a mark on the tube 100 ml. above the surface and to have 100 ml. of rinse water in the bottle in excess of that required for rinsing, so that the flow can be stopped when this top mark is reached. This avoids the possibility of introducing air into the top of the zeolite by attempting to stop the flow of water exactly at the surface.

18.9.2. *Insufficient Volume of Regenerant:* When the volume of regenerant is insufficient to fill the tube completely above the layer, it is advisable to attach a rubber tube to the bottom of the funnel, so that the end will dip slightly into the regenerant. Then, the subsequent procedure shall be similar to that described in Sec. 18.9.1.

18.9.3. *Quantities of Brine Used for Regeneration:* The quantities of brine solution to be used for the initial regeneration of sodium zeolites are shown in the tabulation on p. 741.

18.9.4. *Composition of Rinse Water:* The composition, temperature, pH, etc., of the rinse water shall be the same as that of the water to be treated.

18.9.5. *Volume of Rinse:* The rinse volume (displacement volume) shall be passed through the zeolite at the same rate as the regenerant. After the displacement volume has passed through the test material, the fixed orifice shall be removed from the outlet line. Another fixed orifice, giving a flow rate of 50 ml./min. shall then be inserted, and at the same time the top of the tube shall be connected to the influent waterline, as illustrated in Fig. 5(D). Flow of water through the

zeolite shall be continued until the below-noted hardness can no longer be maintained—either: (1) 10 ppm. (as $CaCO_3$), using *Standard Methods* soap solution; or (2) such as to require five drops of B&B soap solution (*Standard Methods* Field Softener Test). This point shall constitute the end of the rinsing operation and the start of the softening run.

Sec. 18.10—Softening Run

18.10.1. *Starting Point:* The hardness of the effluent at the standard *starting point* of a run shall be: (1) 10 ppm. (as $CaCO_3$), using *Standard Methods* soap solution; or (2) such as to require five drops of B&B soap solution to produce a permanent lather in 40 ml. of the sample.

18.10.2. *Flow Rate and Exchange Velocity:* The standard flow rate shall be 50 ml./min., which corresponds to 12 ml./sq.cm./min., or 3 gpm./sq.ft. The exchange velocity shall be 2.14 mE/l.[8] per min., or 0.0466 grains/cu.ft./min., when softening a water with a hardness of 8.55 mE/l. (25 gpg.). Proportionate corrections should be made according to the area of the tube used.

[8] The unit "equivalents per million grams" (epm.), tentatively approved by the American Society for Testing Materials in 1940, appears to be more consistent when used together with the firmly established "parts per million" (ppm.), because each is a "weight per weight" unit. The abbreviation (epm.), however, introduces a serious inconsistency in that the letter "m" stands for "million grams" rather than for "million equivalents" as might be inferred from its significance in the term (ppm.). Because of this, and also because, in the use of weight per weight units, it is not always clear whether weights of solution or weights of solvent are meant, the Zeolite Manual Committee prefers to use the weight per volume units, i.e., milligrams per liter (mg./l.) and milligram equivalents per liter (mE/l.).

18.10.3. *End-Point:* The hardness of the effluent at the standard *end-point* of a run shall be: (1) 16 ppm. (as $CaCO_3$), using *Standard Methods* soap solution; or (2) such as to require eight drops of B&B soap solution to produce a permanent lather in 40 ml. of the sample.

18.10.4. *Composition of Effluent:* In addition to checking the hardness of the softened effluent at frequent intervals throughout the run, it is essential also to check the pH value, methyl orange alkalinity, phenolphthalein alkalinity and free CO_2 at intervals, particularly at the start of a series of runs with new zeolite.

Sec. 18.11—Calculation of Capacity

18.11.1. *Capacity in the Test:* The results of the individual test runs shall be recorded and, from the volume of water softened, volume of zeolite and hardness of water used during softening, the exchange capacity shall be calculated by the following equations:

$$\text{Capac. (mE/l.)} = \frac{\text{Influent hardness (mE/l.)} \times \text{Effluent (l.)}}{\text{Test material vol. (l.)}}$$

$$\text{Kilograins/cu.ft.} = \frac{\text{mE/l.}}{45.8}$$

$$\text{Capac. (mE/g.)} = \frac{\text{mE/l.}}{\text{g. (105°C.) per l.}}$$

In special cases where appreciable hardness is present in the effluent, the calculations must be corrected for the residual hardness remaining in the softened water.

18.11.2. *Capacity as Received:* It is often desirable to test a shipment of zeolite when received, but before it is put in place. A convenient method of accomplishing this is to prepare a test layer in a piece of pipe of convenient diameter (preferably 6 to 8 in.) and with freeboard sufficient to allow a

least 60 per cent zeolite expansion. The test model should be built with the same depth as its counterpart. The hard water influent shall be metered and the effluent checked volumetrically. The methods described in Sec. 18.11.1 shall be followed, but the salt dosage should be that set forth in the specifications for the particular installation in question. (*See* Supplementary Notes, page 750.)

Section 19—Color Leaching Test

After making a number of exchange capacity runs in the sodium cycle, the zeolite shall be regenerated with 400 ml. 5 per cent brine (NaCl) solution. The brine solution shall be made to flow through the zeolite at 20 ml./min. The material shall then be rinsed with 400 ml. distilled water at 20 ml./min. Rinsing shall be stopped when the water level is 1.26 cm. above the surface of the test material. The water shall be allowed to stand in the unit overnight (preferably for 16 hr.), and then drained into a beaker for the color determination by the procedure of *Standards Methods* (page 13).

Section 20—Porosity

No published data are as yet available to indicate a definite quantitative relationship between the porosity of different zeolites and their practical operational behavior. These procedures are included in order to make available a standardized basis upon which such characteristics of zeolites can be studied.

Sec. 20.1—Detailed Method

20.1.1. *Pore Volume and Porosity:* The pore volume of a given quantity of granules can be expressed by the following equation:

$$\text{Pore Vol.} = \text{Zeolite Vol.} - \text{Void Vol.} - \text{Displ. Vol. of Solid} \quad (1)$$

and the porosity can be expressed as a percentage of the actual summation volume of the individual granules, excluding the void space between them, as indicated in the following equation:

$$\% \text{ Porosity} = \frac{\text{Pore Vol.}}{\text{Pore Vol.} + \text{Displ. Vol.}} \times 100 \quad (2)$$

Unfortunately, it is difficult to define and measure some of the quantities on the right side of the equation.

20.1.2. *Zeolite Volume:* The volume of the zeolite unit can be determined with a considerable degree of precision by several different techniques which give values over a range from a minimum dry volume to a backwashed and drained volume. The difference between these two extremes for materials that swell upon immersion may be as great as two- or threefold, and it becomes a matter of definition which reference state shall be selected in this large possible volume range.

20.1.3. *Void Volume:* The volume of void space between the granules varies, of course, with the type of zeolite volume arrangement selected. It is also difficult to define the point at which fissures in the granules should be regarded as void space instead of pore space. Various techniques of distinguishing between the void space and pore space have been described in the literature, but the methods are complicated and are inevitably limited by the difficulties of definition.

20.1.4. *Displacement Volume:* When the solid granules are immersed, the displacement volume is relatively easy to determine and remains constant regardless of the techniques used for defining the zeolite volume and the void space. A convenient apparatus for determining the displacement vol-

ume is shown in Fig. 7. To operate this apparatus, about 1½ to 3 times the amount of water necessary to immerse the sample of solid granules, whose displacement volume is to be measured, is first introduced into the large burette. All air bubbles below the water level are removed by raising and lowering the dropping funnel slowly two or three times. The level of water is then adjusted just at the bottom of the stopcock in the dropping funnel. The stopcock is then closed and the water level in the burette recorded. Next, the sample of granular material is introduced into the water in the burette. All air bubbles are removed again by raising and lowering the dropping funnel in such a way that a series of backwash treatments are carried out. This process is repeated over a period of time until consecutive readings of the final water level in the burette become constant. In taking the readings of the water level plus the immersed solid, the level of the water in the dropping funnel is, of course, adjusted just at the base of the stopcock as in the initial measurement.

With such equipment, it is possible, with the single volume of water, to backwash a layer of granules until all the air bubbles have been removed. The displacement volume of the solid is given by the difference between the level of the water at the start and that at the conclusion of the backwashing process.

20.1.5. *Quantitative Porosity Relationships:* No data are available to give quantitative relations between the porosity of different materials and their practical operational behavior. In general, the more porous materials are regarded as presenting a greater reactive surface to percolating solutions; hence, it would be expected that they would exhibit a higher capacity within a practical time limit. The more porous materials may, however, be more fragile and may undergo more serious disintegration in long-term operation. Similarly, the more porous materials

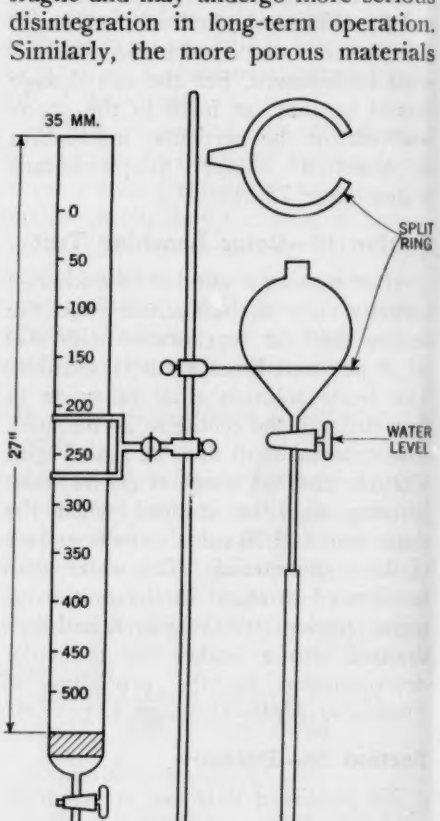

FIG. 7. Apparatus for Displacement Volume Determinations

are regarded by some as more subject to being rendered inactive because of clogging of the surfaces with fine particles of suspended solids. Hence, in addition to the difficulties of defining and determining porosity, there is some

question even as to its theoretical significance in relation to practical operation of granular materials in percolation cycles.

20.1.6. *Quantitative Porosity Measurements:* Of the various quantities related to porosity, the minimum dry volume (MDV) and the backwashed and drained zeolite volume (B&D Vol.) measurements and the displacement volume measurements can be made with the greatest facility and accuracy. Since uniformly sized granules of the same general character, in a given type of volume arrangement, possess the same void space, it seems likely that a given quantity of porous materials exhibits relatively small displacement volumes, e.g., a synthetic siliceous zeolite gave a displacement volume of 27 per cent of its minimum dry volume while relatively non-porous materials gave displacement volumes as high as 100 per cent of their minimum dry volume. The two quantities can be described by the following equations:

$$\% \text{ Displ. Vol. (MDV)} = \frac{\text{Displ. Vol.}}{\text{MDV}} \times 100 \quad (3)$$

or

$$\% \text{ Pores (MDV) + Voids} = 100 - \% \text{ Displ. Vol. (MDV)} = \frac{\text{MDV} - \text{Displ. Vol.} \times 100}{\text{MDV}} \quad (4)$$

and

$$\% \text{ Displ. Vol. (B\&D)} = \frac{\text{Displ. Vol.}}{\text{B\&D Vol.}} \times 100 \quad (5)$$

or

$$\% \text{ Pores (B\&D) + Voids} = 100 - \% \text{ Displ. Vol. (B\&D)} = \frac{\text{B\&D Vol.} - \text{Displ. Vol.}}{\text{B\&D Vol.}} \times 100 \quad (6)$$

20.1.7. *Practical Application of Data:* It will undoubtedly be some time before data of this character can be related to the practical operational behavior of various samples of material in the field. A convenient means of following porosity characteristics on the basis of simple accurate measurements, however, is provided in the technique described, and a mass of routine measurements in the future should serve to establish its significance in testing the quality of granular media in field use.

Sec. 20.2—Short Method—Alternate No. 1

About 40 ml. of oven-dried zeolite shall be poured into 50 ml. water in a 100-ml. graduate. The material shall be agitated thoroughly. Sufficient time shall be allowed for the water to enter the pores, for the released air bubbles to escape and for the water to cool off to room temperature again (placing dried zeolite in water raises temperature). The volume of water displaced by the dried zeolite shall be assumed to represent the *absolute volume* of zeolite (exclusive of interstices and pores).

The adhering moisture from this wet zeolite shall then be removed by means of air-drying, being careful, however, to avoid excessive drying which would again remove some of the moisture from the pores. This zeolite with moisture-filled pores shall then be placed in 50 ml. water in a 100-ml. graduate. In this case the volume of water displaced equals *absolute volume of zeolite plus pore volume.*

To obtain the volume of pores, the *absolute volume* previously obtained shall be deducted from this *absolute volume plus pores:*

$$\% \text{ Porosity} = \frac{\text{Pore Vol.}}{\text{Abs. Vol.} + \text{Pores}} \times 100$$

Sec. 20.3—Short Method—"Wet-Down" Density—Alternate No. 2

20.3.1. *Procedure:* A 100-ml. graduate shall be weighed on a balance. 50 ml. water shall be added and about 50 ml. of material "as received" poured in slowly. The material shall then be stirred well, tamped and weighed. Volume of wet material in graduate and total volume of water plus material shall be noted.

20.3.2. *Calculation of Wet-Down Density:* Wet-down density shall be calculated as follows: Let $a =$ weight of graduate, empty, and $b =$ weight of graduate filled; then $(b - a - 50) =$ weight, in grams, of sample taken (W). Also, let $V =$ volume occupied by sample under water; then $W/V =$ specific gravity of sample in place, and $W/V \times 62.4 =$ pounds of material "as received" to give 1 cu.ft. in place.

20.3.3. *Oven-Dried Samples:* A similar determination shall also be made on oven-dried samples and the result recorded as the weight per cubic foot of the material on a 105°C. dry basis.

20.3.4. *Swelling:* Materials that exhibit swelling tendencies shall be checked at intervals after the start of the soaking period and the volume determined when swelling has ceased.

Section 21—Chemical Composition of Synthetic Siliceous Zeolites

Sec. 21.1—Sampling

The procedure for sampling of zeolites (Sec. 4) shall be followed.

Sec. 21.2—Preparation of Sample

About 10 g. of zeolite to be tested shall be washed in a strong salt solution (about 50 per cent saturation) and then washed with distilled water until free from chlorides. The material shall then be oven-dried (*see* Sec. 11.1). (An air-dried sample may be used if desired, making a correction in weight for the moisture content). The sample is then ready for chemical analysis.

Sec. 21.3—Determinations

21.3.1. *Loss on Ignition:* In a platinum crucible, approximately 1 g. of oven-dried sample accurately weighed shall be heated to a dull red heat for 20 min., then cooled in a desiccator and reweighed. The percentage loss on ignition on the oven-dried sample then equals:

$$\frac{\text{Loss in wt.}}{\text{Wt. of sample}} \times 100$$

21.3.2. *Silica:* About 0.5 g. of oven-dried sample shall be weighed accurately and placed in a platinum or porcelain dish. The sample shall be moistened with distilled water, then 20 ml. of 6 *N* HCl shall be added and the sample evaporated to dryness on a steam or water bath. The procedure shall be repeated by adding an additional 20 ml. of 6 *N* HCl and evaporating to dryness a second time. The material shall then be dried at 105°C. for 1 hr. (*See* Supplementary Notes, page 750.)

The residue shall be redissolved with 5 ml. concentrated HCl followed by 50 ml. distilled water. Following this, the residue shall be filtered, using an ash-free paper, and washed free of HCl, saving the filtrate and washings. The filter paper and residue shall then be placed in a platinum crucible (not porcelain), dried, ignited at 1200°C. to constant weight, cooled in desiccator and weighed (first residue).

The contents of the crucible shall then be moistened with 2 drops of 1 : 1 sulfuric acid, followed by 5 ml. of hydrofluoric acid. The crucible shall be

heated gently under the hood to expel the excess hydrofluoric acid, after which the heat shall be increased until all fumes of sulfuric acid have been expelled. The residue shall again be ignited to 1200°C., cooled in the desiccator and weighed (second residue). Then:

$$\frac{\text{Wt. of first residue} - \text{Wt. of second residue}}{\text{Wt. of sample taken}} \times 100 = \% \text{ Silica in oven-dried sample}$$

The final residue in the crucible shall then be dissolved by fusing with a little potassium bisulfate and dissolving in a little dilute H_2SO_4. This solution shall then be added to the original filtrate and washings and used for the determination of alumina.

21.3.3. *Alumina:* The alumina determination shall be made as follows:

To the solution, evaporated to approximately 100 ml. and free from phosphoric or arsenic acid and elements that would precipitate with aluminum, shall be added 5 g. NH_4Cl and 5 ml. concentrated HNO_3. The solution shall then be heated to boiling and allowed to cool. To the cooled solution shall be added 2–3 drops of an indicator with a pH range between 6.5 and 7.5. Then, dropwise, very carefully, from a burette, shall be added NH_4OH (dilute 1 : 1; free from carbonate) until the alkaline color is obtained (pH 7.5). The solution shall then be heated to boiling and filtered. The precipitate shall be washed with a 2-per cent solution of NH_4NO_3.

The precipitate shall be dissolved in a small amount of hot, dilute HCl and reprecipitated to eliminate, as completely as possible, occluded substances. It shall be ascertained that the solution of the hydroxide by HCl is complete and that the alkalinity in reprecipitation does not exceed the limit recommended.

The precipitate shall be washed free of chlorides, using the 2-per cent NH_4NO_3 solution, and then shall be drained. The filter and its contents shall be placed in a platinum or porcelain crucible, ignited, gently at first until the paper is thoroughly charred, at which time the heat shall gradually be increased. The crucible shall then be covered and heated to a glowing white temperature, cooled in a desiccator and weighed rapidly. The heating, cooling and weighing shall be repeated until a constant weight is obtained.

The precipitate shall then be weighed as alumina (Al_2O_3) unless a reddish tint indicates the presence of iron, in which case it shall be weighed as R_2O_3, determining the iron (Fe_2O_3) separately, and subtracting it from the R_2O_3 reading. (*See* Supplementary Notes, page 750.)

21.3.4. *Sodium Oxide:* Sodium oxide shall be determined on the basis that the sum of percentages (ignited weight basis) of silica (SiO_2) plus alumina (Al_2O_3) and iron oxide (Fe_2O_3) subtracted from 100 equals the percentage of sodium oxide (Na_2O). Also sodium may be determined directly by any standard method of analysis.

21.3.5. *Moisture at 105–110°C:* Moisture shall be determined according to the procedure outlined in Sec. 11.

Supplementary Notes

The italic headings identifying these notes refer to the section of the manual to which they relate and not necessarily to the statements contained in the notes.

Sec. 7.2—Air-Drying Procedure: The air-drying procedure outlined in Sec. 7.2 of the manual may also properly give attention to the following requirements: room temperature shall be maintained at 70°F. ± 10°F.; humidity shall be determined and noted, avoiding test under extreme atmospheric moisture conditions; drafts shall be eliminated.

Sec. 17.1.1—Solutions: If cp. sodium chloride is not used for regeneration of samples, an analysis of the salt used shall be made by accepted methods and the analysis recorded; or an analysis of the brine shall be made and recorded.

Sec. 18.11.2—Capacity as Received: The rinse rate of flow or length of rinse (in time) shall be as required for the type of zeolite used or as called for in general specifications for particular installations. These approximate: for greensand, 20–25 min.; for high-capacity greensand, 35–40 min.; for carbonaceous and resinous zeolites, 40–45 min.; and for synthetic zeolites, 55–65 min.

Sec. 21.3.2—Silica: The largest and most troublesome error in the silica determination is the one due to the solubility of the SiO_2 in the HCl. The amount of freshly precipitated SiO_2 that dissolves in HCl depends on the following conditions: (1) the amount of acid present; (2) the strength of the acid; (3) the temperature; and (4) the length of time the silica is in contact with the acid. There may be other conditions governing the solubility of SiO_2 in HCl, but these seem to be the principal ones. By far the most important is the amount of acid used. Most chemists use acid of about the same strength to treat the dehydrated silica. The assays are brought to a boil, insuring the same temperature, and are boiled for a fairly uniform length of time. Few, however, consider the importance of using a definite amount of acid. When a small amount of SiO_2 is present, the amount dissolved is proportional to the quantity of acid solution present and not to the amount of SiO_2 in the sample.

Sec. 21.3.3—Alumina: (*a*) The precipitation of aluminum hydroxide is complete between pH 7.0 and 7.5. Indicators showing an alkaline reaction at 7.0–7.5 should be used. With a pH exceeding 10, the hydroxide is appreciably soluble, aluminum later appearing with the calcium and magnesium precipitates.

(*b*) Since the carbonate is precipitated by addition of lime in the distilling flask, the freshly distilled ammonia is best kept in a ceresine or paraffin bottle. It will then remain free from silica, which it invariably contains when confined in glass bottles.

(*c*) It is advisable to filter as soon as possible after making the precipitation of $Al(OH)_3$. Long heating of the mixture containing the aluminum precipitate is objectionable because: (1) The solution is apt to become acid, due to the decomposition of ammonium salts and the volatilization of ammonia. (2) The precipitate will become slimy and will be difficult to wash and filter; it is preferable to redissolve and again precipitate if this condition occurs. (3) The CO_2 of the air is apt to be absorbed by the solution, causing the precipitation of calcium carbonate, etc., if the solution is exposed for any length of time. (4) Silica from the beaker will contaminate the precipitate.

(*d*) Washing the precipitate with ammonium nitrate prevents the aluminum from passing through the filter and keeps it from packing. It favors the formation of the insoluble hydrogel form of the hydrate while preventing the formation of the soluble hydrosol.

Calculation of Threshold Odor

By Harold A. Thomas Jr.

FEW phases of the development of water treatment have been as interesting as the measurement of odor. Despite imperfections, the odor test has assumed ever-increasing usefulness in production of acceptable water. At present, with shortages of material and personnel, the improvement of this essential test takes on added importance in maintenance of efficiency and economy in water plant operation.

Interest in the nose as a measuring instrument has been further increased by the likelihood that no man-made device will supersede it for some time. It was true that, for a period, during the development of the electron tube, which has revolutionized other analytical procedures, there was a reasonable hope that an apparatus would be evolved which would free the odor test from the idiosyncracies of the human nose. Such hope it appears is not to be realized; the olfactory sense with all its deficiencies remains among the most sensitive devices for detecting small amounts of matter known to man. Unfortunately it is one of the least precise instruments man is obliged to use.

Notwithstanding the fact that for over a half-century the water-dilution method has been employed in odor testing, no general agreement exists today as to what precision of odor measurement is attainable. Until agreement is reached, much of the sphere of utility of the test must remain unmapped. Present practice, involving the comparison of competitive activated carbons and accurate dosage for reasons of economy, demands a more precise method of measuring odors than provided in the 1936 *Standard Methods* (1) technique.

The important question at the present time is whether or not the precision of odor measurement may be increased to meet the new demands. Expert opinion diverges at this point. Some doubt whether the precision can ever be made sufficiently high; others have shown experimentally that under certain conditions a very high degree of precision is attainable. Conflicting opinions and test data have left doubt in the minds of many as to the status of the test. In view of the great value of precise odor measurement to the water profession, it is important to determine whether the discrepancies can be resolved in a rational framework.

On the basis of a review of published work and additional tests reported herein, it is optimistically believed that previous experimental differences may be explained; in fact, that they may be

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traced to two or three main sources. There can be no doubt that far more precision is possible than has generally been obtained.

An element of compromise exists, however; certain desirable features must be sacrificed in the modifications necessary to obtain the requisite degree of precision. This degree, moreover, sometimes can only be obtained at the expense of considerably more laboratory routine. Although there are undoubtedly persons physically incapable of performing the refined test and although there are certain odors with abnormal characteristics that defy measurement, it appears to be certain that odor determination may be placed on a sufficiently precise level to achieve the ends desired.

To evaluate more fully the potentialities of the nose in the precise measurement of odor, it is worth while to consider briefly the important developments of the past that have a bearing upon precision.

Water Dilution Method

Early work in the field of odor measurement has been discussed by Gamble (2) and Fair (3); more recent developments are presented by Hulbert and Feben (4), Spaulding (5, 6) and in the report of the A.W.W.A. Committee on Activated Carbon Research (7). Significant developments may be summarized as follows.

1. *A marked difference exists in characteristics of odors met in water works practice.* This alone accounts for much experimental discrepancy and conflicting opinions. Some odors can be measured precisely; others cannot. Basic research has conclusively shown that although the weight of any odorous substance required to produce a sensation is small, compounds differ with respect to: (a) the concentration that may be detected and (b) the percentage increase (or decrease) that may just be detected.

These facts are well known and need mention only to emphasize that, when all sources of error are reduced to the minimum level feasible, inherent differences in the chemicals producing odor will inevitably cause differences in the precision attainable at different water treatment plants.

Experiments have shown that, with a few odorous compounds, the water dilution method fails completely. This failure occurs with substances immiscible in water. With such substances, the pressure of the odorous vapor is independent of the proportions of odor-free water and sample, thereby rendering the test result meaningless. These chemicals are not commonly encountered, but their presence undoubtedly serves to explain occasional erratic test results. In the event that the water dilution method proves unsatisfactory with a given odor, recourse may be had to the air dilution method developed by Fair and Wells (8).

Despite the existence of unusual chemicals, however, it is probable that the water dilution method is generally satisfactory for routine tests.

2. *Odor-free water exists as an abstraction approached only imperfectly in practice.* The very use of the term "odor-free" betrays a confusion, for there can be no complete absence of odor any more than complete absence of light, heat or sound. What is commonly implied by the term is subthreshold water. Baylis (9) and Helbig (10) have indicated the importance of the error in test results due to contamination of the dilution water at concentrations below the perception

level. Experiments with different dilution waters show that the error is particularly large with certain chemicals such as phenol. The indications are that this source of error may be minimized but not eliminated. There are practical limitations upon the amount of care that may be expended in the preparation and storing of odor-free water. The method of preparing dilution water must be selected on the basis of the type of odor to be measured and the precision desired. Fortunately, the influence of the dilution water is readily subjected to investigation by direct comparison in the individual laboratory.

3. *The variation in the level of sensitivity of the olfactory sense must be taken into account in odor measurement.* Actually there are two characteristics of the nose that influence the test result: a certain temporal mean level of sensitivity and an irregular fluctuation in sensitivity from the mean level. With the level of sensitivity constantly changing, even under the most carefully controlled conditions, it is to be expected that odor measurements will reflect the variation, giving rise to discrepancies inherent in the test.

Some of the reasons for the fluctuation in the level of sensitivity are physiological; others are psychological. These have been discussed by Fair (3), Gamble (2), and more recently by Feben (4). The established facts having a direct bearing upon the question of precision are as follows:

a. The rate of fatigue is approximately proportional to the concentration sniffed. This emphasizes the importance of devising experimental techniques in which most of the flasks tested are in the vicinity of the threshold value. Such flasks have low concentrations of odor and hence cause less fatigue.

b. The use of the blank refreshes the sense only imperfectly and does not stop the slow downward trend of sensitivity due to fatigue. It does serve a useful function in clearing the olfactory cavity of odor residuals after testing each dilution.

Probably one of the most significant developments has come with the use of the blank in providing a basis of comparison with each dilution of the sample tested. Spaulding has advocated this procedure and has shown that the increase in precision brought about is considerable. In comparing each sample with the blank, the observer is able to detect very small differences in intensity and therefore to establish the threshold with a high degree of precision. Recent work has indicated the advisability of renewing the blank at frequent intervals during the test.

c. The nose is fatigued at different rates by different odors. Since most natural waters contain a mixture of different odorous substances, all with different rates of fatigue and all affected in this respect in a different manner by dilution, it is evident that no high degree of precision of measurement can obtain unless fatigue is combatted by every expedient.

d. Some observers, including Aronson (11) and Feben (4), have mentioned the hypothesis that odorous particles entering the nose must go into solution with the mucous secretion. The sensation of odor is dependent on the resultant concentration which in turn is dependent not only upon the number of odor molecules entering, but also upon the amount of secretion. Since mucous secretions are known to vary with the individual, his state of

health (colds, etc.) and the temperature and humidity of the atmosphere, it would appear that this circumstance alone would permit only a very low degree of precision of odor measurement. Others, including Zwaardemaker (12), have contested the assumption that odorous molecules must go into solution in order to produce a sensation. They point out that the cilia of the olfactory cells protrude through the covering of mucus. Furthermore the drying of mucus during such conditions as those accompanying rhinitis is confined almost exclusively to the Schneiderian membrane and not the delicate olfactory membrane. The incapacity for smelling during colds is due to swelling which obstructs the passage of air to the olfactory cavity and not due to changes in mucous secretion on the olfactory nerve.

If it is true that the odorous molecules do enter the mucous secretion, they probably do not go into a solution in the usual sense of the word. The process is more likely to be one of adsorption on the mucous surface and, accordingly, a process in which the amount of the secretion is of less importance than if a true solution were formed.

Although these causes for variation in sensitivity are not the only ones operative, they would appear to be among the more significant. They suffice to indicate that, despite all precautions, a residual discrepancy between test results is to be expected.

Fortunately, in the case of an individual, the rate of variation in the level of sensitivity is not fast. Normally it may be quite constant for a period of several minutes. Hence, test results by a given observer measured over a short period of time do not reflect changes in sensitivity that would be introduced if the tests were conducted over a more protracted period. Realization of this has brought about the introduction of "parallel tests" in which a few samples are tested simultaneously. Usually the number of samples that may be tested is limited to two or three because of fatigue. Parallel testing has been advocated by Spaulding (5) and Hassler (4), who have shown that the improvement in the precision of measurement with this procedure is indeed significant. Of course, parallel testing and interpretation of results on a relative basis does not help the operator determine the absolute threshold odor (T.O.) of the effluent so as to aid in determining exact dosages of odor-eliminating chemicals. It does, however, enable him to compare the raw water with the treated and to compare the effects of different carbons. The adoption of this technique in many plants is a definite indication of its utility. Experimental results directly bearing on this point will be presented.

4. *Precise odor measurement is possible without the use of nosepieces.* This problem has received much attention. Although nosepieces are not generally used in routine water testing it should be pointed out that nearly all the investigators who carried out the extensive research of the nineteenth century found them indispensable in refined odor measurement. The chief advantage of the nosepiece is that it covers the nostrils and directs the odor to the olfactory cleft, excluding all extraneous odor that may be present. Against this undisputed advantage may be listed the following disadvantages:

a. The additional interior surface of the nosepiece decreases the precision attainable due to the adhering of many types of odorous molecules to the glass or metal surface. Gamble (2) has

shown that errors from this source may occasionally be large but that they may be corrected by using two nosepieces of different length.

b. The proper cleaning of the nosepiece between each application to the nose imposes an additional amount of work that may be objectionable in routine testing.

c. An undesirable amount of fatigue may be occasioned by the additional inhalation required to fill nosepiece with the odorous vapor. It has been demonstrated by the use of colored vapors that most nosepieces, particularly the larger ones, are not filled spontaneously to saturation by simply immersing the open end of the tube in the vapor above the freshly shaken contents of the flask. Time is required for the establishment of equilibrium and it is usually expedient to hasten the process by inhalation to draw up the vapor. Such inhalation occasions unnecessary fatigue.

The weight of these advantages and disadvantages will differ with the individual; the matter should be decided independently by the observer himself. One significant fact seems to be established. In testing without a nosepiece the shape of the flask used has an important bearing on the precision attainable. The most important characteristic of the flask is a mouth wide enough to admit the nose, but not so wide as to admit extraneous odors or diluting air during the instant of sniffing. A second desirable feature is that the flask be fitted with a ground glass stopper making possible a more vigorous and uniform shaking of the contents.

5. *The temperature of the sample during the test markedly affects the threshold level and, to a lesser degree, the precision.* Generally, however, temperature does not have any pronounced bearing upon the precision with which the threshold may be estimated. It is true that experimental results indicate a progressive decrease in precision as the temperature is increased beyond 30°C. The loss of precision is not large if the sniffing is conducted quickly and in a uniform manner. The loss is probably caused by irregular cooling of warmed flasks by evaporation while testing. This cooling effect is enhanced when nosepieces are used. Since the effect is slight, it would appear that considerations other than that of precision attainable should govern the selection of the temperature to be used.

6. *Fundamental in odor work is the applicability of the Weber-Fechner Law.* The Weber-Fechner Law applies with varying degrees of approximation to the various senses of sight, hearing, etc. It states that the increase in sensation recorded on the brain is proportional to the relative (rather than the absolute) increase in external stimulus. Applied to the sense of smell, the increase in concentration of an odorous substance necessary to cause a just detectable increase in the sensation of odor is a constant fraction of the original concentration. Hence, sensation increases in arithmetic progression as stimulus is increased in a geometric progression.

That this law has a definite bearing upon the problem was conclusively shown by Gamble (2) in 1898. In 1933, Fair (3) pointed out the implications of the law pertaining to test procedure and interpretation. Chief among these is the requirement that the amount of sample be decreased by a constant percentage in each succeeding flask of the series. This procedure results in a uniform distribution of the odor intensities on the sensation scale

and promotes efficiency in testing. Fair also concluded that, in line with the theory, the odor should be measured on an arithmetic sensation scale (called the pO scale) instead of the geometrically increasing dilution scale based on the stimulus. Other scales, such as the pH and the decibel scale for sound, are founded on similar principles. This method of reporting results has many advantages. Most important is the ease with which the work of different observers may be correlated and averaged; also the computation of deviations from average values is greatly facilitated.

It is not absolutely necessary, however, to use a sensation scale; the apparent objectivity of the stimulus scale in odor work appears to recommend it to many. One disadvantage that pertains to the pO scale is that it must be computed by means of logarithms to the unfamiliar base of two.* This, of course, is no disadvantage so long as the *Standard Methods* dilution table, based upon a 50-per cent decrease in the amount of sample in succeeding dilutions, is employed. But this dilution table cannot be used in precise odor evaluation, hence the values in the pO scale are no longer simple integers but must be computed logarithmically.

While it is possible to avoid the use of logarithms by using a stimulus scale based on dilution ratio, serious errors may result from failure to take into account the non-linearity of such a scale. It is possible to employ arithmetic manipulations on a geometric scale if the range of values treated is small. The difference between the arithmetic and geometric mean, for example, is negligible if the T.O. values differ by no more than, say, 20 per cent; but if the percentage difference is large, such as 400 or 600 per cent (often arising in odor work), arithmetic methods fail entirely. Even in so called "weighting" procedures, in which levels of sensitivity of different observers are adjusted by factors based on arithmetic averages, considerable error may be introduced and incorrect conclusions formed as the result of treating a geometric scale by arithmetic methods. As will be seen, these difficulties may be overcome only by using an arithmetic sensation scale.

7. Unless the odor test is conducted on a "blindfold basis" the result will bear a fictitious degree of precision. The "blindfold technique" is an important innovation in odor testing. The observer is not necessarily blindfolded, but is otherwise kept in ignorance of the sample and dilution of the flask in hand. It is quite evident that, unless this is done, extraneous psychological influences may enter and seriously distort the test result. Recent testing procedures, unlike that of the original *Standard Methods* test, have been unanimous in specifying some sort of "blindfold technique."

In summarizing the developments that have been made, it may be said that, while certain factors operate so as to introduce inaccuracies inherent in the test, advantage may be taken of others that greatly reduce the margin of error. Incorporating these features into the test, the following question arises: Does the improved test give results precise enough to meet practical requirements? The answer is yes, subject to the qualification, inevitable in

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* The pO, which is the threshold value upon the sensation scale, is related to the T.O., which is the threshold dilution on the stimulus scale, as follows:

$$pO = \log_2 (T.O.) = 3.32 \log_{10} (T.O.)$$

where:

$$T.O. = \frac{\text{Vol. odor-free water} + \text{Vol. sample}}{\text{Vol. sample}}$$

all physical measurement, that increased precision may involve more routine testing.

The experimental program described below was undertaken primarily to determine how much routine is necessary to attain the degree of precision demanded in water practice. Such a program is seen logically to divide into stages. The first of these is the development of more refined mathematical tools to replace present coarse approximate ones that fail to meet the needs of the situation. It will be seen that mathematical refinements, though perhaps somewhat abstruse in theory, definitely bring out the potentialities of the improved test without making the computations essentially more difficult. The second stage consists of the accumulation of data covering a wide range of waters and observers, using the improved technique and calculation. Then the connection between precision and routine will be evident, and questions regarding the utility of the test may be answered.

While the second stage of the experimental program is not entirely complete, significant results have been obtained. These, together with some recalculation of published data, are presented and clearly delimit the capabilities of the human nose.

Calculation of Threshold Odor

In order to measure the precision attainable in odor testing, it is necessary first to consider the problem of translating the positive and negative responses of the observer to a numerical value for the T.O. concentration.

If an observer tests, at random, a series of flasks containing odorous water in a geometric dilution progression, his results will fall into three zones. The first of these contains the responses from the lowest dilutions (containing large amounts of the sample) and these will all be classified as positive. A second zone corresponds to the highest dilutions which will all be negative. The third zone, corresponding to intermediate dilutions, will contain both positive and negative responses. This is a region of uncertainty on the part of the olfactory sense and has aptly been called by Spaulding the "twilight zone." It is in this zone that anomalous results appear; frequently an observer will identify as negative a dilution lower than one he has previously identified as positive.

It is evident that the number of dilution steps in the twilight zone depends in part upon the percentage reduction in odor concentration between adjacent dilutions. The smaller the reduction the more difficult it is for the nose to distinguish difference in intensities. Therefore, the width of the twilight zone increases with a decreasing percentage reduction in adjacent dilutions. If the reductions are made sufficiently large (i.e., 50 per cent, as in the *Standard Methods* test) it is possible to contract the twilight zone to its minimum width of one dilution step. This, however, renders the test incapable of giving precise values of T.O. On the other hand, if the percentage reduction is made small in order to increase the precision attainable, anomalous results appear and must be taken into account.

Although the twilight zone represents a zone of uncertainty, it is quite incorrect to assume that the width of this zone constitutes a measure of the degree of reproducibility in odor tests. By taking the center of the twilight zone, as located by a consistent method of calculation, experiments definitely indicate that a much higher degree of reproducibility is attainable. The degree of precision thus attained depends upon the method of calculation used.

Some methods are much more efficient than others and, consequently, provide a more satisfactory basis for computing T.O.

At present the method by which test results in the twilight zone are manipulated is to "recess" the positives to fill anomalous negatives; that is, the procedure is to reduce arbitrarily the width of zone to one dilution step and to assume that the T.O. concentration of this altered arrangement is the same as that of the actual test result. It will be shown that this procedure does not lead to the development of the highest precision attainable. Several other methods of calculating the T.O., which develop more precision than the method of recession, have been tested. One need only to refer to similar cases, such as the "oyster score" and the "colon index," both outmoded methods based upon recession of anomalous results. These have been replaced by more satisfactory methods of calculation, which suggests that a more refined method may exist to calculate the results of the odor test. A recalculation of published results, together with work done in the author's laboratory, verifies this suggestion. In many tests there is a marked gain in precision with the use of more efficient methods of calculation.

A series of tests have been made upon a variety of odorous samples. Tests have been conducted upon raw and treated natural waters as well as upon odor-free water dosed with odorous chemicals. A variety of dilution tables were employed varying from a 44- to a 5-per cent reduction of sample in adjacent flasks. In the testing procedure every known modification increasing precision was introduced. The T.O. of each test was calculated by five different methods and the degree of reproducibility developed by each investigated. The five methods may be explained most readily by an example.

Using a 25-per cent dilution table, the following responses are reported by an observer for a raw water at 24°C:

D:	1.00	1.33	1.77	2.37	3.16	4.21	5.61	7.48	9.99	13.3	17.7	23.7
n:	0	1	2	3	4	5	6	7	8	9	10	11
Response:	+	+	+	+	−	−	−	+	−	−	*	−

* Dilution not tested.

Where D = odor concentration = $\frac{\text{Vol. sample} + \text{Vol. odor-free water}}{\text{Vol. sample}} = 1/(1 - 0.25)^n$; the usual geometric stimulus scale

n = no. of the dilution; an arithmetic sensation scale

The five methods of calculation are as follows:

Method A: This is the method of recession in which any anomalous positives (7.48) are carried to the left to fill anomalous negatives. After the transfer is made, the T.O. is defined as the value of the odor concentration corresponding to the highest dilution positive. In the example, T.O. = 3.16.

Method B: In this method, the T.O. is defined as that value of D halfway between the next to the highest dilution positive (2.37) and the next to lowest dilution negative (4.21). In the example, T.O. = 3.16, which, by coincidence, checks with Method A. If the halfway point falls between two values of D, their geometric mean is taken as the T.O.

Method C: The values of n for the three highest dilutions positive (2, 3, 7) are added to the values of n for the

three lowest dilutions negative (4, 5, 6) and the mean n computed (4.5). The T.O. is the value of D corresponding to the mean value of n. In the example, the mean n of 4.5 lies halfway between D values of 3.16 and 4.21. Hence, T.O. $= \sqrt{(3.16)(4.21)} = 3.65$. Often, however, it will be satisfactory to use ordinary methods of interpolation to transfer from one scale to another. This will depend upon the dilution interval and the precision desired.

Method D: The T.O. is taken as being halfway between the highest dilution positive (7.48) and the lowest dilution negative (3.16). Hence, in the example, T.O. $= \sqrt{(3.16)(7.48)} = 4.86$.

Method E: In this method it is necessary to know, approximately, the value of a quantity called the *coefficient of variability*. The computation is based upon an equal number of negative and positive responses, including all responses in the twilight zone plus as many of the non-anomalous responses as possible. The only reasons for not including a response outside the twilight zone are: (1) that the inclusion of the response would result in an unequal number of positive and negative responses, or (2) that the response is separated from those included by a dilution interval larger than that between those included. In the example, all responses would be included with the exception of the one for dilution 23.7. The T.O. then may be computed by the following equation:

$$\text{T.O.} = \left[\frac{\text{Sum of (all positive } D\text{'s})^a}{\text{Sum of (all negative } D\text{'s})^{-a}}\right]^{\frac{1}{2a}} \quad (1)$$

Here the symbol a is the coefficient of variability. This coefficient depends upon the training and experience of the observer and his natural variability in level of sensitivity. On the basis of test data available at present, Table 1 gives applicable values of a.

TABLE 1

Values of the Coefficient of Variability

a	Characteristic of Observer
0.0–1.5	Poor discrimination; marked variation in sensitivity; little or no experience in odor determination
1.5–3.0	Average discrimination and variability; some experience in odor determination
3.0–6.0	Superior discrimination; only slight variation in sensitivity; considerable experience in odor determination

These values are tentative since only limited data are available. Moreover there is some evidence that, for a given observer, a varies slightly with the odor tested and changes somewhat depending on fatigue. In the majority of cases of routine testing, however, the number of types of odor dealt with are few. Consequently, a single value of the coefficient should ordinarily suffice. The development of the full precision of the determination is predicted upon a knowledge of the coefficient a for the observer. It may be estimated from Table 1 or more closely evaluated by analyzing test results over a period of time to determine that value of a giving the highest precision, as measured by the degree of reproducibility. For many, a may be assumed to be 2.0 or 3.0 without greatly affecting the precision attained. Thus, in the example, if $a = 2.0$, substituting in Eq. 1:

$$\text{T.O.} = \left[\frac{1.00^2+1.33^2+1.77^2+2.37^2+7.48^2}{3.16^{-2}+4.21^{-2}+5.61^{-2}+9.99^{-2}+13.3^{-2}}\right]^{\frac{1}{4}} = 4.26$$

Eq. 1 was derived, making use of the "method of maximum likelihood" of

statistical theory which, in general, yields the most efficient statistics (13). The derivation is similar to that used in deriving the formula for the "most probable number" used in quantitative bacteriology. The T.O. calculated by Method E may be defined as the *modal* T.O. (M.T.O.), since it is more likely to represent the true threshold than any other T.O. value.

Tests have shown that Method E gives results with precision significantly higher than the other methods if proper values of the coefficient a are used. The chief value of Method E would appear to be in research wherein, as in the present case, it may be used as a basis for evaluating other methods. If a high degree precision is not required, a simpler method of calculation may suffice. Of the methods tested, Method D has proved to be the most satisfactory, with Methods C, A and B following in that order. It may readily be shown that Method E becomes identical with Method D when the coefficient of variability a is very large and becomes identical with Method A_1,* when a is taken as zero. Hence, T.O. values computed by Method E must fall between those computed by Methods A_1 and D. There are theoretical reasons for supposing that Method B should provide efficient measures of T.O., but experience has shown it to be less reliable than Methods D and E. Like E, C falls between A and D and may be taken as an approximation to E. Method C, unlike other simply calculated methods, did not often deviate widely. In no series of tests was A found to give the best reproducibility, although it did not consistently give the worst precision. In fact, results with some observers, when calculated by Method A, gave precision that did not compare unfavorably with other methods, with the exception of the more elaborate Method E.

It should be emphasized that the various methods give different results only when anomalous responses occur. If these do not appear, all methods give the same degree of precision. Hence the benefit of using more involved methods of calculation is realized only in testing in which anomalous responses frequently occur. In ordinary testing of some types of water it will be found that a sufficient degree of precision may be obtained by using a dilution interval sufficiently large so that anomalous results occur only occasionally. At present, it appears that such waters are not common. Adequate precision can scarcely be developed if the dilution interval is greater than 25 per cent.* With a dilution interval of this size anomalous results appear in many tests; at 15 per cent they may be the rule rather than the exception. A considerable difference is noted among different types of water; samples from one supply regularly gave anomalous results at 35- and 44-per cent intervals, while samples from another source gave mostly non-anomalous tests at 10 per cent. Tests with a 5-per cent dilution interval consistently gave anomalous responses.

In Table 2 is presented a series of parallel tests on tap water, using a 15-per cent dilution table, which brings out the differences in the various methods of calculation. In each test, parallel determinations were conducted on

* Defined as ½ dilution interval higher than Method A.

* The dilution interval $S = 25$ per cent means that the amount of sample is reduced by 25 per cent in each successive dilution.

each of two identical portions of a sample of tap water, the observer being ignorant of their identity. Since the deviations were not large, it is permissible to use the arithmetic average deviation to compare the reproducibility as computed by each method. The mean value of all the average deviations for the five tests are: A, 8 per cent; B, 10.4 per cent; C, 7 per cent; D, 6.4 per cent; E, 5.2 per cent. Method E gives the least variation and Method B the highest. Easily computed Method D is somewhat more precise than A, the method of recession. These results are fairly typical although they show a somewhat higher degree of precision than generally obtained with a 15-per cent dilution table.

In general, Method D appeared to be the most satisfactory. It combines ease of computation with reliability of measurement; consequently it was used in computing the data presented in the following sections. It should be remarked that, with inexperienced observers or persons with marked variability in sensitivity, Method D may not be as satisfactory as other methods in that it will occasionally give erratic results, in line with the theory developed in connection with Method E.

This does not mean that in tests with unusually wide twilight zones

TABLE 2

Comparison of T.O. Values Obtained by Various Methods of Calculation for Five Sets of Parallel Odor Measurements on Tap Water

Dilution Interval, S = 15 per cent

n	D	Test 1—8/17/42 (a)	Test 1—8/17/42 (b)	Test 2—8/18/42 (a)	Test 2—8/18/42 (b)	Test 3—8/20/42 (A.M.) (a)	Test 3—8/20/42 (A.M.) (b)	Test 4—8/20/42 (P.M.) (a)	Test 4—8/20/42 (P.M.) (b)	Test 5—8/22/42 (a)	Test 5—8/22/42 (b)
0	1.00	+	+	+	+	+	+	+	+	+	+
	(1.08)										
1	1.17	+	+	+	+	+	+	+	+	+	+
	(1.27)										
2	1.38	+	+	+	+	+	+	+	+	+	+
	(1.50)										
3	1.63	+	−	+	+	+	+A BCDE	−	+	−	+
	(1.77)										
4	1.92	−AB C	+ D	−	+	+A BCDE	−	+	−	−	+
	(2.08)										
5	2.25	− E D	+A E C	+	−	−	−	+A BC	+ D	+	+A BCDE
	(2.44)										
6	2.65	−	+ B	+ D	−A BC E	−	−	− DE	+A E C	−ABCD E	−
	(2.87)										
7	3.12	+	−	+A E C	+ D	−	−	−	+ B	+	−
	(3.39)										
8	3.67	−	−	+ B	−	−	−	−	−	+	−
	(3.98)										
9	4.32	−	−	−	+	−	−	+	−	+	−
	(4.67)										
10	5.08	−	−	−	−	−	−	−	−	−	−
	(5.51)										
11	5.98	−	−	−	−	−	−	−	−	−	−

Result	Test 1—8/17/42 T.O.$_a$	T.O.$_b$	Avg. Dev.*	Test 2—8/18/42 T.O.$_a$	T.O.$_b$	Avg. Dev.*	Test 3—8/20/42 (A.M.) T.O.$_a$	T.O.$_b$	Avg. Dev.*	Test 4—8/20/42 (P.M.) T.O.$_a$	T.O.$_b$	Avg. Dev.*	Test 5—8/22/42 T.O.$_a$	T.O.$_b$	Avg. Dev.*
Method A	1.92	2.25	8%	3.12	2.65	8%	1.92	1.63	8%	2.25	2.65	8%	2.65	2.25	8%
Method B	1.92	2.65	16%	3.67	2.87	12%	2.08	1.77	8%	2.44	3.12	12%	2.65	2.44	4%
Method C	2.08	2.44	8%	3.30	2.87	7%	2.08	1.77	8%	2.51	2.87	7%	2.72	2.44	5%
Method D	2.44	2.08	8%	2.65	3.12	8%	2.08	1.77	8%	2.65	2.44	4%	2.65	2.44	4%
Method E	2.18	2.34	4%	3.17	2.95	4%	2.08	1.77	8%	2.54	2.74	4%	2.75	2.44	6%

* Avg. Deviation = $(T.O._a - T.O._b) \div (T.O._a + T\ O._b)$.

Method D is less satisfactory. Even in such tests, the method usually provides greater precision. An instance of this may be seen in the interesting case recorded by Spaulding (5) in which Observer F, who was usually consistent, suffered a temporary period of uncertainty of response and gave an unusual number of anomalous results in contrast to Observer E who turned in a perfect record with no anomalous responses on the same sample. If Observer F's record is calculated by Method D an excellent agreement with Observer E appears, despite the unusual number of anomalous results. On the other hand with the usual method of calculation (Method A) the results of the two observers show poor correlation.

Precision of Odor Measurement

Precision depends upon the extent of the dispersion of the individual measurements. Precision may be computed from the usual dilution (stimulus) scale using ordinary arithmetic methods if the range of values represented is not excessive. Often in averaging the results of different observers, however, large differences in sensitivity are encountered and arithmetic calculations with T.O. values fail to give satisfactory measures of dispersion. In fact, occasionally, the average deviation will be larger than the arithmetic mean, implying the existence of negative threshold values, which is impossible. At best, ordinary average (or standard) deviations, whether or not computed on a percentage basis, give an inaccurate representation of the nature of the dispersion of items about the mean. Experimental results (in accord with the Weber-Fechner Law) consistently exhibit larger deviations above the mean than below the mean.

The correct way to represent the dispersion may be illustrated by the following example: Three observers report T.O. values for a sample as 1.5, 2.0 and 8. The necessary computations are given in tabular form as follows:

Obs.	*T.O.*	$\log_{10}$ *T.O.*	(*log T.O.* − *0.460*)
A	1.5	0.176	0.284
B	2.0	0.301	0.159
C	8.0	0.903	0.443
Avg.		0.460	0.295

Antilog (0.460) = 2.90, the geometric mean
Antilog (0.460 − 0.295) = 1.46, lower limit of average range
Antilog (0.460 + 0.295) = 5.70, upper limit of average range
Avg. range is 1.46 : 2.90 : 5.70, or, expressed as percentage of geometric mean, 50 : 100 : 197

If, however, the deviations had been calculated arithmetically, using the T.O. values, the average range would be 26 : 100 : 174. Although in this example the methods show approximately the same mean deviation, only the logarithmic calculation indicates the proper distribution of the average range about the central value. A further advantage of the logarithmic calculation is that it supplies the geometric mean. This value provides the best estimate of the true mean T.O. Often it differs substantially from the arithmetic mean, which is unduly influenced by extreme values.

It is of course unnecessary to use a logarithmic table (or pO values) in calculation of average range about the geometric mean. A simple *n*-scale, such as shown in Table 2, may be used in place of logarithms. As a matter of fact, *n* values *are* logarithms of the *D* values (to the base $1 \div (1 - s)$). In this way all calculations are very simple, and the results may be expressed in the usual way by transferring from the *n*-scale to the *D* scale by ordinary meth-

ods of interpolation. A large average range indicates a wide dispersion of individual test results and implies a low degree of precision of measurement.

Precision attained depends upon: (1) experimental technique; (2) dilution interval; (3) characteristics of observers; (4) type of odor; (5) period over which tests extend. In order to investigate any one of these, the others must be held constant. This is experimentally possible using natural raw and treated waters, except in tests designed to determine variability over extended periods of time, in which case changes in the sample vitiate the results. In these tests, chemical substances were used to provide dilutions of constant odor intensity.

1. *Technique:* The experimental technique employed was essentially that recommended by Spaulding (5). Some results, however, were obtained using the "one-man" test to be described. Both techniques gave practically equivalent results.

2. *Dilution Interval:* It is reasonable to suppose that an optimum dilution interval exists for a given observer and type of odor. Precision depends primarily upon the number of independent measurements; the mean of several measurements is more precise than the individual measurement itself. Consequently, in tests with low dilution intervals, having many tests in the vicinity of the threshold, the T.O. is more precisely established. In odor work, however, due to fatigue and sensitivity variations, there is a lower limit to the dilution interval. Moreover, quite aside from questions of precision, a practical restriction exists upon the number of dilutions tested, due to the limited time available in routine testing.

In order to find the optimum interval for a variety of natural and treated waters the following laboratory procedure was employed: (a) An observer tested a sample in dilution tables of 15, 25 and 35 per cent (some testing also being done with 5, 10 and 44 per cent). With each dilution table he made two T.O. evaluations simultaneously on undiluted portions of a sample (often a third test on another sample was made, but these results are not pertinent). The two T.O. values obtained supplied an average range which was expressed as a percentage average range by multiplying the T.O. values by a factor such as to raise the geometric mean to 100. (b) The two parallel determinations were repeated by the observer with other dilution tables using the same sample. (c) The average ranges obtained thus by a single observer for each dilution table were combined logarithmically with similar values with the sample by other observers. (d) Finally, the average ranges for different samples were combined. The final ranges, one for each dilution interval, are presented in Table 3.

TABLE 3

Influence of Dilution Interval

Dilution Interval, *per cent*	No. of Observers	No. of Samples	Average Range		
			Lower	Mean	Upper
15	5	25	89	100	112
25	6	24	82	100	122
35	6	22	77	100	130

It is evident from the data that the precision is increased considerably with the use of low dilution intervals. A few tests were conducted with a dilution interval of 5 per cent. These exhibited still higher precision, but not as much as was expected, indicating the influence of fatigue. The optimum in-

terval is generally in the vicinity of 10–15 per cent, although samples from some sources gave satisfactory precision with an interval of 25 per cent.

3. *Characteristics of Observer:* In comparing the sensitivity levels of different observers, the following procedure was employed: (a) All observers available tested a given sample using independently prepared dilution tables with an interval of 15 per cent. The average range of T.O. values about the geometric mean was computed and, for purposes of comparison, was multiplied by an appropriate factor so that the geometric mean became 100. (b) The average range thus obtained was combined logarithmically with results from other samples. The overall average range for all the samples, properly weighted for number of observers, was 69 : 100 : 145. This reflects a considerable variation between observers and is in accord with previous data on the subject. No especially significant difference between the deviations obtained with raw and treated waters was found.

As was noted by Spaulding, the broad range obtained could be narrowed considerably by omitting the results of certain observers whose sensitivity varied widely and in an erratic manner. Consistent observers, working with samples of one type of odor (say, water from one source), appear to have a mutual variation measured by an average range of 77 : 100 : 130, about the same order as obtained by a single observer in random determinations on a given sample.

4. *Type of Odor:* Although this phase of the program has not been completed, present indications are that precision attainable with different types of odor are very marked. Samples from one source tested gave an average range for all observers of 93 : 100 : 108, whereas from another source an equal number of samples gave an average range of 68 : 100 : 147. Other samples were measured with precision between these extremes. Such wide variation is in line with classical work on odor characteristics of pure chemicals. More recently, Helbig (10) reported large differences in precision with which the gravimetric concentration of different chemicals at the threshold could be determined. Undoubtedly the precision attainable depends to a great extent upon characteristics of the odor itself.

5. *Period Over Which Tests Extend:* In order to determine quantitatively the effect of variability in sensitivity upon the precision, the following procedure was carried out in the laboratory: (a) An observer made a pair of odor determinations in parallel upon a sample. (b) This procedure was repeated at random times during the day, giving, in some cases, as many as six sets of pairs. (c) In order to extend the period of testing beyond a day, standard dilutions of odorous chemicals were used in place of natural waters and the tests repeated over a period of several days. Phenol and tricresol solutions were employed. The dilutions were renewed periodically to maintain constant odor intensity.

The computation may be illustrated by consideration of results for Observer II, by whom four pairs of T.O. evaluations were made on tap water on August 24, 1942, each pair being determined simultaneously. The computation is made in two parts as shown in Table 4.

Typical results are shown in Table 5 which contains the record of three observers who have the longest consecutive records from samples from a given source.

TABLE 4

Calculation of Variation in Sensitivity With Time

Part 1. Precision in Parallel Testing

Test	T.O.$_a$	T.O.$_b$	log T.O.$_a$	log T.O.$_b$	$\frac{1}{2}$ (log T.O.$_a$ + log T.O.$_b$)	Geom. Mean	Average Range*		
							Lower	Mean	Upper
1	1.63	1.38	0.212	0.140	0.176	1.50	92	100	109
2	2.65	3.67	0.423	0.565	0.494	3.12	85	100	118
3	4.32	3.12	0.636	0.494	0.565	3.68	85	100	117
4	1.92	1.92	0.283	0.283	0.283	1.92	100	100	100

Part 2. Precision in Random Testing Over Period of a Day†

Test	log T.O.$_a$	log T.O.$_a$ − 0.389	
1	0.212	0.177	Antilog 0.389 = 2.45 geom. mean T.O.$_a$
2	0.423	0.034	Antilog (0.389 − 0.141) = 1.77 lower limit
3	0.636	0.247	Antilog (0.389 + 0.141) = 3.39 upper limit
4	0.283	0.106	Avg. range = 1.77 : 2.45 : 3.39
Avg.	0.389	0.141	On basis of 100 = 72 : 100 : 139

* Mean average range = 90 : 100 : 111; computed as follows:

$$\sqrt[4]{92 \cdot 85 \cdot 85 \cdot 100} = 90$$
$$\sqrt[4]{109 \cdot 118 \cdot 117 \cdot 100} = 111$$

† A similar computation for T.O.$_b$ yields an average range of 69 : 100 : 144. The combined average range = $\sqrt{(69)(72)}$: 100 : $\sqrt{(144)(139)}$ = 70.5 : 100 : 141.

TABLE 5

Variation in Sensitivity With Time

Type of Sample	Observer	No. of Samples	Duration of Testing, *days*	Average Range of parallel tests			Average Range in random tests		
				Lower	Mean	Upper	Lower	Mean	Upper
Treated	I	16	16	86	100	116	75	100	133
"	II	16	16	89	100	112	78	100	128
"	V	12	12	79	100	127	63	100	159
Raw	I	6	6	89	100	112	58	100	173
"	II	7	7	91	100	110	77	100	130
"	V	10	10	82	100	122	74	100	135
Phenol	V	—*	8	90	100	111	79	100	127
"	I	—*	16	88	100	114	71	100	141
Tricresol	V	—*	6	85	100	118	69	100	145

* On the average 3 parallel tests (6 T.O. determinations) were made per day.

Judging from the data in Table 5 there would not appear to be any very significant differences in precision with different observers or samples. A very striking and significant difference, however, is noted between random and parallel testing. The increase in precision that comes with parallel testing is two- to three-fold. Variations over a period of a day do not seem to be greatly less than those experienced over several days, although this point is obscured by the fact that the more extended tests had to be conducted with odorous chemicals rather than natural waters.

A study of the foregoing tests together with that from other observers tested indicates that in routine testing the precision attainable with parallel tests amounts to about 10–15 per cent of the T.O. as measured by the average deviation. In random tests the average deviation was of the order of 25 to 40 per cent of the T.O. This means that, although absolute odor evaluations are far from precise, samples may be compared on a relative basis with considerable exactitude.

Development of One-Man Test

Although the blindfold technique has definitely improved the odor test, it has made the determination essentially a task for two (or more) persons. This may be a disadvantage in the small plant, particularly at the present time. It seemed desirable, therefore, to try to develop a technique requiring only one man, yet which would retain much of the precision of the two-man test.

A promising method has been evolved which is based upon the use of a revolving wheel (Fig. 1) to aid in the random selection of dilutions and blanks without the aid of a diluter. The analyst simply prepares the dilutions in accordance with any suitable dilution table. The number of flasks required to span the twilight zone will be determined by experience. Placing the dilutions for the various samples at random on the wheel, the observer spins the latter and, after an indefinite number of turns, selects any bottle at random, with the eyes averted to avoid learning its identity. In this way all bottles are tested, each unknown dilution being compared directly with a blank and placed either in the positive

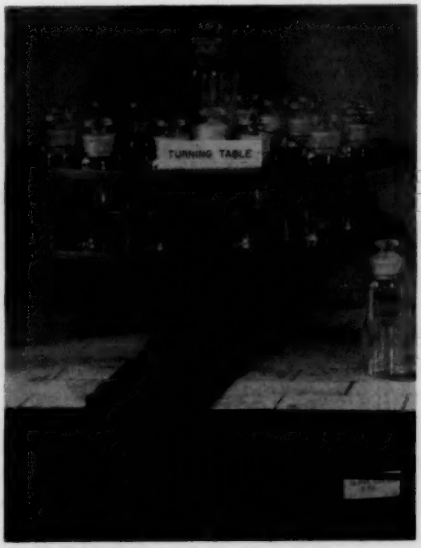

FIG. 1. Turning Wheel for Randomizing Order of Dilutions Tested

or negative group. After all responses have been made, the observer records the result. Dilutions of two or three samples may be placed on the wheel simultaneously and tested in parallel. An additional small wheel may be used to randomize the sample and the blank if desired.

The precision attained with this technique compares favorably with that of the usual blindfold test. In a few samples there was evidence that the odor intensity changed shortly after dilution.

With this type of sample it is to be expected that the precision of the one-man test will be less. It would appear, however, that this does not often occur and does not constitute an appreciable source of error. The method does possess one additional advantage: after the dilutions are once prepared the test may be repeated a few times before the sensitivity level changes. The additional data thus obtained may considerably improve the precision of the average T.O. values.

Rating of Activated Carbons

Having investigated the precision attainable in the individual odor test, the next problem to consider is that of comparing the odor-removing efficiencies of competitive activated carbons. The most direct approach is to dose equal portions of a given raw water with equal weights of the two or three carbons being tested. The dosage is such that one carbon (the standard) brings about the required odor reduction. After treatment odor intensities are measured by one or more observers and the problem becomes essentially that of deciding, on the basis of the precision of the test, whether the measurements differ significantly enough to warrant rating of the carbons in order of efficiency. The precision will be determined primarily by the number of independent T.O. values obtained. These may be either from different observers or from replicate tests by one observer. It is a statistical truth that precision (but not necessarily accuracy) may be improved by increasing the number of determinations. Any degree of precision is theoretically obtainable even in odor measurement. Practical restrictions, however, limit the degree actually obtained. The number of observers cannot often be large; in many plants the issue may be decided by one person. The number of replicate tests is fixed by considerations of fatigue and available time. Consequently, it will not always be possible to decide between two carbons on the basis of a few T.O. determinations. The important consideration is to determine how far average T.O. values must deviate before the difference may be deemed significant.

In forming a judgment of the relative value of two carbons there is a temptation to use formulas of the following type:

$$\text{A.D.}_M = \text{A.D.}/\sqrt{N} \quad \ldots\ldots (2)$$

$$\text{P.E.}_M = \text{P.E.}/\sqrt{N} \quad \ldots\ldots (3)$$

where:

A.D._M, P.E._M = average deviation and probable error of the mean
A.D., P.E. = average deviation and probable error of the individual test
N = no. of independent tests

The use of formulas such as these in measuring the reliability of averages has repeatedly been shown to be incorrect when N is a small number, as it almost invariably is in odor work. Equations 2 and 3 are derived on the basis of classical sampling theory which is applicable only when the numbers dealt with are large. They are applicable, for example, in life insurance or agricultural experimentation, where the number of persons or plants is very large. This is not the case in carbon evaluation, hence Eqs. 2 and 3 cannot be used.

A satisfactory statistical theory dealing with small numbers has been developed. It is to a large extent the work of R. A. Fisher (13). On the basis of this theory the statistical significance of experimental results in activated carbon comparisons can be tested.

In order to test properly the significance it is necessary to use a sen-

sation scale of odor intensity. Arithmetic methods applied to T.O. values are particularly unreliable. Despite "weighting" procedures, which can only partially correct for differences in sensitivity, serious errors in interpretation have been found to occur with incorrect mathematical analysis.

The principles involved may best be explained by means of an example, in which three carbons were compared by four observers in parallel tests on a sample of raw water. The T.O. values obtained are as follows:

Observer	*Carbon Sample*		
	H	*X*	*Y*
I	9.99	20.4	31.6
II	6.48	7.48	13.3
III	1.77	3.16	6.48
IV	5.61	4.21	9.99
Geom. Mean	5.04	6.71	12.8

It is apparent that Carbon Y is less effective than the others. Considerable doubt exists, however, as to whether or not the test has brought to light any significant difference between Carbons H and X. Borderline cases such as this occur and may only be decided on the basis of a statistical computation, which properly takes into account differences in levels of sensitivity, as follows:

(1) Obs.	(2) Log_{10} of T.O. Values		(4) Difference	(5) Deviation	(6) (Deviation)²
	H	*X*	*Col. (3) − Col. (2)*	*Col. (4) − 0.125*	*Col. 5 squared*
I	1.000	1.310	+0.310	+0.185	0.0342
II	0.811	0.874	+0.063	−0.062	0.0038
III	0.248	0.500	+0.252	+0.127	0.0161
IV	0.749	0.624	−0.125	−0.250	0.0625
Sum	2.808	3.308	+0.500		0.1166
Avg.	.702	0.827	+0.125		

Next, a value, t, is determined from the formula:

$$t = \bar{d}\sqrt{\frac{N(N-1)}{\Sigma d^2}} \quad \ldots\ldots\ldots (4)$$

where:

$\bar{d}$ = mean difference in logs = 0.125
Σd^2 = sum of squares of deviations = 0.1166
N = no. of observers (or replicate comparisons) = 4

Therefore:

$$t = 0.125\sqrt{\frac{4\,(3)}{0.1166}} = 1.27$$

The question of significance may then be decided by reference to Table 6.

TABLE 6

Values of t *for a 5-per cent Level of Significance*

N	t_5	N	t_5	N	t_5
2	12.71	7	2.45	12	2.20
3	4.30	8	2.36	13	2.18
4	3.18	9	2.31	14	2.16
5	2.78	10	2.26	15	2.14
6	2.57	11	2.23	16	2.13

If the t obtained by calculation is smaller than the value of t_5 from Table 6, the difference in the carbons may not be considered significant. This is the case in the example, since the value of t calculated (1.27) is less than that of t_5 in the table (3.18). If a greater value than that in the table is obtained, the difference may be considered significant.

The rationale of the test may be explained in the following manner. If the odor-removing efficiencies of the two carbons H and X were identical, it should not be expected to get iden-

tical mean T.O. values (that is $t = 0$), due to the imperfect precision of the odor test. Taking the imperfections into account, however, if the carbons are equally effective, only a 5-per cent chance exists that a comparative test would show a discrepancy as great as that measured by the value of t_5 in Table 6. Consequently, if the calculated value of t from the test exceeded t_5, there would be reason to suspect that the carbons were not equally effective. The 5-per cent level is arbitrary, but is commonly used in sampling problems of this type.

The important point is that the limited precision in ordinary carbon comparison may preclude the establishment of a significant carbon rating. About 25 per cent of comparisons made in the laboratory were indecisive when based upon four replicate comparisons. Of course a rating can be established if a sufficient number of additional tests are carried out. This, however, will not always be practicable. In the final analysis it will be necessary to test doubtful comparisons for significance.

Conclusions

From this study, then, it has been shown that:

1. The odor test may be conducted to yield more reliable results than have generally been obtained.

2. The improvement in precision pertains chiefly to comparative results obtained in parallel testing.

3. The development of the full precision of the test and the determination of the significance of results depend upon the use of proper mathematical methods.

4. Activated carbons may be compared by the threshold test, but occasionally an excessive number of tests may be necessary to establish a significant rating.

The author gratefully acknowledges his indebtedness to Professor Gordon M. Fair; much that has been done is an extension of his ideas. Acknowledgment is also due to Norman S. Stearns for many helpful suggestions and for assistance in the laboratory.

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Pioneering by the Paducah Water Works

By Louis R. Howson

THE original water works plant at Paducah, Ky., was constructed in 1885 at a time when Paducah was a city of less than 10,000 people. In the original installation, water was drawn through a 16-in. intake which then as now extended across the channel of the Tennessee River and took its supply from the Ohio River, the superior settling qualities of which were recognized at even that early date.

Water was pumped from the Ohio by direct suction with "Holly" vertical pumps and discharged into the distribution system without treatment. There was no distribution storage other than that in a 22 × 175-ft. standpipe located on the pumping station grounds. Incidentally, this standpipe was constructed of wrought-iron plates and upon recent inspection, after 57 yr. in service, showed very little evidence of corrosion of either plates or rivets.

The original distribution system consisted of 13 mi. of pipe, all of cast iron, varying in size from 4 to 16 in. In the next 35 yr., the distribution system had been increased to 41 mi. and at the present time, 57 yr. after the initial construction, contains 83.3 mi. of pipe.

A paper presented on October 20, 1942, at the Kentucky-Tennessee Section Meeting, Paducah, Ky., by Louis R. Howson, Alvord, Burdick & Howson, Engrs., Chicago.

The original franchise had 40 yr. to run, expiring in 1924. Ownership of the water works changed three times in the first 3 yr. after building, but thereafter, until purchased by the city 42 yr. later, was largely owned and directed by Muscoe Burnett, who, with his associates, contributed much toward the pioneering later described.

In 1903, a rapid sand filter plant was constructed. For the first 9 yr. coagulation was effected in a steel tank. This tank is still used when the concrete coagulating basins are being cleaned. Necessarily, filtration required the adoption of double pumping. Direct-acting low lift pumps were installed and the original vertical "Holly" pumps were used for high service.

The original 16-in. cast-iron intake was superseded in 1903 by a 31-in. steel intake pipe which was later paralleled by a duplicate 36-in. cast-iron intake laid in 1926. The entire water supply for Paducah is now drawn through the cast-iron intake, the outlet end of which is supported upon a pile grillage some fifteen or more feet above the river bottom. A 6-in. high-pressure pipeline parallels the 36-in. line out to the intake structure, where it terminates in six brass nozzles so placed that their jets are directed toward the screen. If the screen clogs or a mud bar forms around the screen

this high-pressure line undermines and scours the deposit so that the river current will carry it away. There has never been a stoppage or serious obstruction to this intake.

Prior to the 1937 flood, in which 90 per cent of the Paducah area was submerged, there had not been a single interruption to water service since operations started in 1885, a remarkable record considering the topography, Ohio River floods and the fact that there was substantially no high service storage until 1937. This plant was built immediately following the Ohio River flood of 1884 and passed through the 1913 flood without curtailment of service. The 1937 flood elevation was seven feet higher than any previously recorded at Paducah. Water service was maintained in 1937 until practically the entire population was evacuated. It was resumed before the people returned to their homes.

The water works was privately owned from its beginning in 1885 until 1930 when it was acquired by the city under an arbitration proceeding.

Present Status of System

At the present time there are over 7700 active consumers, services are 100 per cent metered and daily pumpage approximates 3 mgd. Until 1925, due to the original franchise provisions regarding rates, only 3 per cent of the water services were metered. In the engineers report of 1925 the following statement was made:

"At the present time, the Paducah Water Plant is pumping approximately 6,750,000 gpd. This is an excessive amount. In extreme hot or cold weather this amount is increased to 10,000,000 gpd. . . . After a careful study, it is the conclusion of the engineers that the present average pumpage of approximately 6,750,000 gpd. might be reduced by meters to slightly less than 3,000,000 gpd."

The 1941 average pumpage was 2,965,000 gpd.

There are now three turbo-centrifugal low lift pumping units with a total capacity of 18 mgd. There are nine rapid sand filter units with a rated capacity of 9 mgd., six installed in 1903 and the other three equipped in 1941. The high lift pumping equipment consists of two turbo-centrifugal units, each of 8 mgd. capacity, and one of 6 mgd. capacity. These discharge into the distribution system and a 5-mil.gal. reinforced concrete reservoir built in 1938 on the bluffs west of the city. The original standpipe is used for wash water storage.

Filter Plant

The Paducah Water Works has never been afraid to pioneer and in so doing has contributed much to the forward progress of water supply. A few of the milestones in which Paducah pioneered deserve mention.

The filter plant has already been mentioned. It is well to point out, however, that the concrete filters at Paducah are one of the very earliest installations of that type in the country, following by only two years the initial Little Falls, N.J., installation. Nine filter boxes were built in the original construction, but only six were equipped with an underdrainage system. The laterals and strainers in the original filters were replaced by perforated cast-iron laterals in 1930. The additional three filter boxes were equipped with modern high-rate water wash piping and equipment in 1941. The six original filters are still

equipped for air and water wash, a method which has demonstrated its ability to keep the sand clean over a period of 38 yr. The new filters have more adequate wash trough capacity and are equipped with surface wash of the grid type.

Treatment Plant

So far as is known to the writer, Paducah had the first dry feed machine used in the feeding of chemicals for filtration of water. It was designed in 1913 by John Holmes, then Chief Engineer, and H. C. Mitchell, present Chief Engineer of the Paducah Water Works. The rate of feed was regulated by the velocity of flow in the channel carrying the discharge from the low lift pumps. The water turned a paddle wheel of the steamboat type connected through changeable gears to the orifices in the chemical hoppers which were located vertically above the raw water channel into which the chemicals dropped. It therefore operated much as the modern proportional feeders with meter control. The changeable gears were found necessary to meet the fluctuating chemical demands of the variable turbidity in the Ohio River water. Their use resulted from observations of country sawmill operations by Mr. Mitchell. Ingenuity here as always resulted in progress.

The reinforced concrete coagulating basin was built in 1912. It is unique in that its floor is a series of square hoppers, each provided with a quick-opening hydraulically operated mud valve. These valves are operated without the necessity of draining the coagulating basin. The 45-deg. slopes were sufficient for satisfactory operation. Flocculators were installed in the first pass of the multiple-pass basin in recent years.

Pumps

Another notable pioneering adventure of the Paducah Water Works was the installation in 1908 of three turbine driven centrifugal pumps. These units, all of which are still in service, were among the earliest and, at that time, were the largest turbo-centrifugal units installed. The turbines operate at 12,500 rpm. geared down to centrifugal pumps on a speed reduction ratio of approximately 10 to 1. In recent years all of the direct-acting pumping equipment has been removed. The plant now includes six turbo-driven centrifugal pumping units, the later installations, of course, being of improved design and slower rotative speed. The fact that the original units have been in continuous service up to recent times and will remain as auxiliary units for years to come, however, is a tribute to the quality built in by the manufacturer and the maintenance and care with which they were operated.

Private Franchise

The original 40-yr. franchise, which expired in 1924, contained provisions relative to rates which made it practically impossible for the company to meter and survive. At the expiration of this franchise, the city and company each selected an engineer to co-operate in an appraisal of the property and advise as to future policies, including rates. From this study there was developed a pioneering type of franchise as applied to water works. It was what might be termed a "cost-plus-fair-return" franchise. In brief, it specified a rate base determined during the life of the franchise by adding net book additions to the value agreed upon as of January 1, 1925. The company was entitled to earn a gross revenue sufficient to cover operating

expenses, depreciation in the amount of 1 per cent on the rate base and 7½ per cent on the rate base for fair return. A rate schedule was developed to produce this amount of revenue. Any surplus over the above requirements was specified as going into a revolving fund designated as "the adjustment reserve." If at any time this reserve exceeded $25,000, the excess earnings thereafter would be paid to the city. If the earnings in any year failed to earn the amount specified, the deficiency could be withdrawn from the adjustment reserve.

Among other provisions of this franchise was that specifying payment for fire protection service. This service was to be paid for on the basis of $10 per year for each fire hydrant plus 1¼¢ per linear foot of pipe per inch diameter. The low hydrant charge of $10 per year encouraged the city to authorize hydrants liberally and the compensation for larger size pipe removes the incentive for a company to lay small mains. Experience has shown that the application of this method has resulted in securing unusually good fire protection for the city. At Paducah fire hydrants are used for fires only. There are 66 sprinkler plugs from which the city may take up to 20 mil.gal. per year for street and sewer flushing. All are metered. The city used about half of this amount. The ratio of metered water to pumpage varies between 85 and 90 per cent, a reflection of good meter maintenance, a tight pipe system and a dense clay soil which forces even a small leak to the surface.

Largely as a result of this type of franchise, and particularly that part relating to fire protection cost, the Paducah distribution system was increased nearly 100 per cent in mileage within the next ten years. As of the present time, it consists of 2.38 mi. of cast-iron pipe per thousand population, a figure nearly 20 per cent above the general nation-wide average. The average size of pipe is also liberal, being approximately 300 tons per thousand population, a figure about 10 per cent above the national average. There are now 977 fire hydrants in this city of 35,000 people. So efficient is the water works in its fire protection service that in the last report of the National Board of Fire Underwriters there was not a single recommendation marked with a star with respect to the water supply. If the proof of the pudding is in the eating, truly the Paducah pioneering "cost-plus-fair-return" franchise was successful.

Municipal Management

In 1930 the city purchased the water works system through an issue of water revenue bonds. The property was purchased at approximately $2,000,000, an appraisal fixed by an arbitration board of engineers. The city immediately set up a board of water commissioners. Here again the Paducah situation is somewhat unique in that each of the three board members is appointed for life and is free from any political influence. Thus safeguarded, the water board has attracted to its membership outstanding public-spirited civic leaders. This board wisely continued to operate the property as though it were privately owned. The city is charged and pays for fire protection service under the same schedule of rates as was set up in the cost-plus-fair-return ordinance. Rates for service, both domestic and industrial, are the same as therein provided. Most of the old operating personnel is still on the job.

Another unique and not the least successful pioneering adventure of the Paducah Water Works was the appointment of a woman Secretary and Treasurer—Miss Lois Sutherland, who is one of the few feminine members of the American Water Works Association and one of the Association's most conscientious convention attendants. The Paducah Water Board realizes that her attendance at conventions and section meetings is a good investment for the department.

Financial Status

It is not surprising that under this kind of municipal management the Paducah Water Works is successful financially. The 1941 revenue was approximately the same as the present national average, *viz.* $6.50 per capita; 21 per cent was derived from fire protection service. The operating and maintenance expenses were only $65,000 or 28 per cent of the revenue, being somewhat less than $2.00 per capita.

Since the plant was acquired by the city about eleven years ago, it has added $365,394 to capital account, has a cash depreciation reserve of $41,859, has retired $130,000 worth of bonded indebtedness and has purchased in the open market, at a cost of $15,722, some of its own outstanding bonds. Approximately 25 per cent of its revenue has been expended for these items. Bond interest is currently earned approximately 1½ times, after setting aside $16,816 for depreciation. Where the entire investment is being amortized within the life of most of the property, the setting aside of depreciation in addition to amortization is a stringent requirement.

In summary, it can well be stated that there has been real pioneering work in every phase of the Paducah Water Works from its selection of the best raw water source through the construction of its long river intake, its early filtration plant, its early use of turbo-centrifugal pumping equipment, its pioneer application of dry-feeding equipment, the "cost-plus-fair-return" franchise provisions under private operation, the creation of the life-term water board under municipal ownership and the appointment of a woman executive. Paducah may well be proud of its contributions toward the advancement of water works progress and its accomplishments in administering its most essential utility service.

Development of Tapping and Valve-Inserting Machines

By J. Arthur Jensen

A SURVEY of the appliances used in water works for pumping, transportation and delivery of water from the source to the consumer indicates that all such devices generally follow established patterns which the industry has been reluctant to modify or change except in the event of absolute necessity.

The development of a product by progressive steps may be illustrated by beginning with the service pipe, following its logical development and observing the improvements brought forth. Very little has been written on this subject so that certain speculation may be indulged in quite freely in discussing the development.

Water works texts and old ordinances often refer to ferrules formerly placed in mains for attachment of service pipes. A tap was made by drilling a slightly tapered hole and then driving in a ferrule, sometimes tinned to insure a better attachment to the iron. This could be done with or without pressure in the main. The former would no doubt give the operator a brief shower bath during the manipulation. The large number of times that this operation was used against pressure conditions and the frequent shower baths no doubt gave rise to the idea of a device which was gradually developed into that in use today. Thus we now have fine machines which drill and tap the main under pressure and insert the threaded cock ready for the service line without attending annoyances.

It is reasonable to consider that this improvement suggested to some fertile mind that the idea be extended to larger sizes than those used for house services. The construction of a branch pipe with an ordinary tee and gate meant interruption to service, extra excavation and considerable cutting and fitting before pressure could be restored and the connection completed.

Sleeve Tee and Valve

Ingenuity came to the front to bring the so-called sleeve tee and valve into being. The tee casting is a split section designed to be fitted around the main. It is held by bolts or clamps. The joints, two on the main and one on the branch, are made up on the as yet uncut pipe. The gate is attached by a spigot with locking lugs and a leaded or bolted joint. The cutter housing is attached to the outside flange of the gate which is fully open. The shaft of the machine is pushed forward until the center drill is against the pipe. A set-collar is secured on the shaft and the drilling is done either by hand or power. The drill centers the cutting

A contribution by J. Arthur Jensen, Engr. (recently retired) Water Works Dept., Minneapolis, Minn.

shaft and the cutter follows through and, when the cut is made, the cutter is withdrawn, with the cut disk of pipe, through the gate, which can then be closed. The housing of the cutter attached to the gate during the operation prevents the loss of water except for that which is retained outside the closed gate and machine housing. When the cutter is unbolted the laying of the branch pipe proceeds without further delay.

This device is extremely ingenious and has proved itself of great value to the water industry. It is now taken as a matter of course, but it is well to remember that no department of any size can get along well without it.

Valve-Inserting Machine

Following the same line of thought it might be assumed that the originator of the sleeve and valve tapping machine had further visions. His line of reasoning might have been to consider that, if a side gate could be attached to a main under pressure and without interruption to flow, it should also be possible to cut in a gate in a pipeline without interruption to flow or pressure. As is well known such a device was contrived and has been used in the industry for many years.

The valve inserting machine is used for inserting gate valves, 4 in. to 20 in. in diameter, in mains without shutting off the water. To do this it is obvious that a short section must be cut out of the pipe, the gate placed in the opening and the extra space made up by some form of external adjustable piece. To contend with the flowing water and pressure involved, operations have been worked out by a mechanical magician aided by the use of a portable chamber and certain auxiliary devices. The chamber is the "magician's cabinet" and all the internal operations are performed "sight unseen" within its recesses.

A double-ended cutter, in two halves, is placed on the main and the pipe is cut almost through in two places. An outside split sleeve is bolted and packed around the pipe close to one of the cuts. The housing is then placed and bolted around this sleeve and pipe, enclosing the cutting machine. The joints of the housing at the pipe are leaded and calked. This housing space is divided into two parts by a horizontal slide valve, the lower chamber enclosing the pipe and the upper section forming a dome directly above the position for the setting of the gate. When the cut is finished, the cutter and pipe section are raised by the cutting shaft rod, the slide valve is closed and the top of the dome is removed to take out the cut section. The gate to be inserted is then suspended in the dome, cover attached, the slide valve reopened and the gate lowered into place between the newly cut ends of the pipe. One hub end of the gate is larger than the other to receive the spigot of the external split sleeve. This is forced in by outside-operated jacks until the small hub is seated on the other end of the cut pipe, centered by guides and temporarily made watertight by rubber gaskets. The gate body has two arms and a pedestal to guide it to placement inside the housing. The top sections of the "magician's cabinet" are then removed and the three new joints are leaded and calked. The lower housing is removed and the insertion is completed and the gate ready for use.

The sleeve and valve tapping machine is the most used device and has proved itself of the highest importance to the industry. The insert gate is used where it is imperative that the water

should not be shut off during the placement of the gate. This is particularily the situation on important supply lines or in congested, high value districts in the larger cities, where water pressure must be maintained at all times. Such lines, however, are large in diameter, and the development of the insert gate had apparently reached the limit of its application at about 20 in. in diameter. But the urgency of the need stimulated further work and resulted in eventual solution of the problem.

Application to Large Valves

The "downtown" water system of Minneapolis was built in the late Seventies and early Eighties, taking its supply from the adjacent Mississippi River. The pressures were moderate. In 1897 the supply was taken from a new location above the city, an equalizing reservoir was built and the pressures raised considerably. The congested, high value areas were supplied by a "loop" of 24-in. mains. The gates on these mains had been designed for the lighter pressures so that when they were operated under emergency conditions it was found the stems of the gates would invariably buckle when nearing the full closure position. To replace these gates by the ordinary process would have required numerous closures and interruptions of fire protection and general service as well as increasing operating troubles with the old gates.

In 1917, F. W. Cappelen, City Engineer, placed his problem before Denis F. O'Brien, President of the A. P. Smith Mfg. Co., with the proposal that a certain number of new 24-in. insert valves be supplied and installed at designated points in the downtown areas. Mr. O'Brien agreed to take this proposal under advisement. The writer attended the Annual Convention of A.W.W.A. at St. Louis in 1918, with instructions to learn from Mr. O'Brien what progress had been made in providing these special gates. Mr. O'Brien explained that up to that time no insert larger than 20 in. had been made. He pointed out that a 24-in. insert gate could not be cut in by the same methods as the smaller gates, since the housing would be too large and cumbersome to withstand ordinary pressures and if attempted would require too much rigging. The weight of the gate would be such that it could not be controlled satisfactorily from the outside by the usual methods. By a departure from the "magician's cabinet," however, an entirely different method and design was being developed.

Standing in the lobby of the Planters Hotel, Mr. O'Brien sketched his proposed design on the back of an envelope. He explained that the body of the proposed gate would serve as its own housing for the installation and, when finished, would remain in place as part of the gate for regular use. The gate body was to be made in three parts. It was to be split to fit it around the pipe, but the bonnet was to be the usual type. To furnish space for interior operations a 24-in. gate would take on the external proportions of a 30-in. gate body and would be equipped with the necessary mechanical features for the installation.

Procedure of Insertion

The procedure was to be as follows: When the pipe was exposed and cleaned, a double-ended pipe cutter, in two halves, would be attached around the main. With the cutter adjusted, the cutting would begin and continue

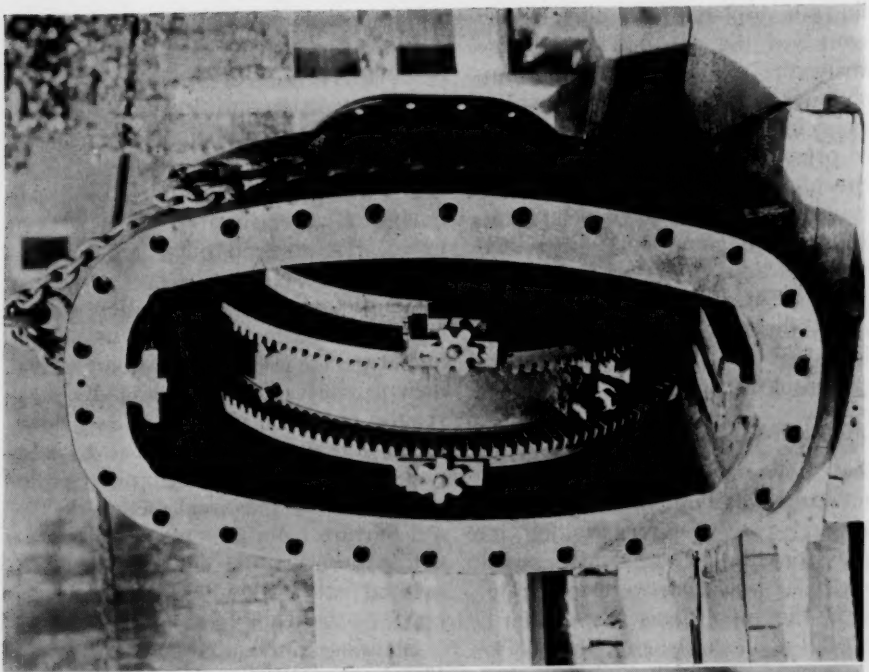

FIG. 2. Double-Ended Pipe Cutter

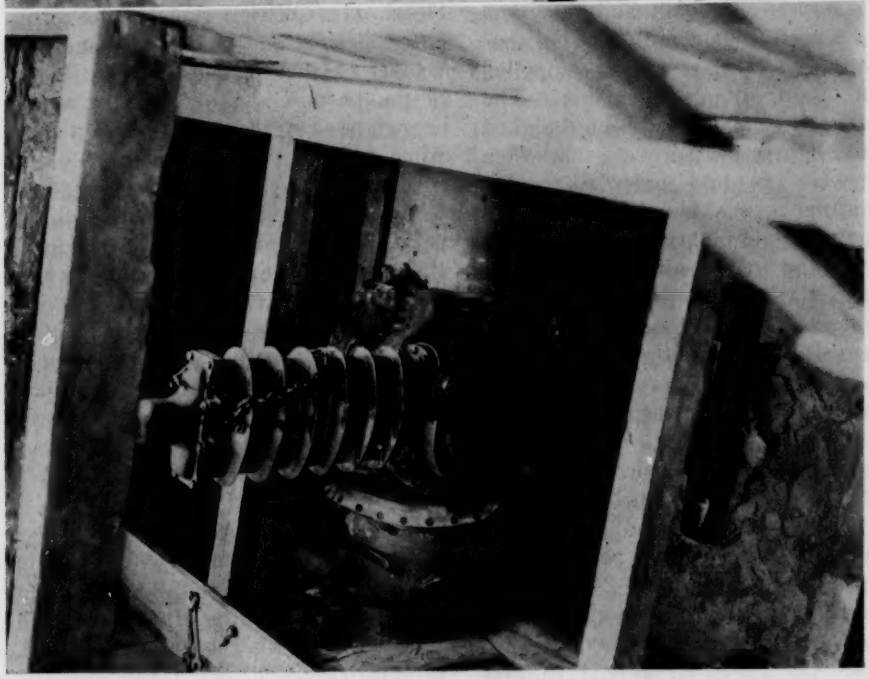

FIG. 1. Set-up for Installation of First 24-Inch Gate Valve; showing slide valve dome

until nearly through the walls of the pipe. At this point the lower part of the gate would be fitted on, enclosing the cutter, and joined by heavy bolts along the axis of the pipe and leaded bell ends. This partial housing was to be designed in such a way that movable seat rings would be provided for later adjustment. A temporary or construction bonnet would then be attached to the body equipped with stuffing box openings, one for a shaft controlling the cutter and pipe section and another for the shaft operating the cutter. On the top of the middle body piece a long bronze dome would be attached containing a slide valve operated by an external stem. This slide valve would serve to divide the gate body into two compartments separating the main from the bonnet section. Then the cutting of the pipe would continue. The cutter rings would be equipped with star wheels, which in the course of each revolution would strike a fixed cam and thereby set up the feed of the cutters. When the cut was completed, water would fill the lower and temporary gate body, and the cutter and section of pipe would be free and capable of being moved into the bonnet on guides. The slide valve would be closed and the bonnet section drained and removed. The regular gate bonnet would be brought forward, containing the stem, disks and gearing complete and be attached to the gate body.

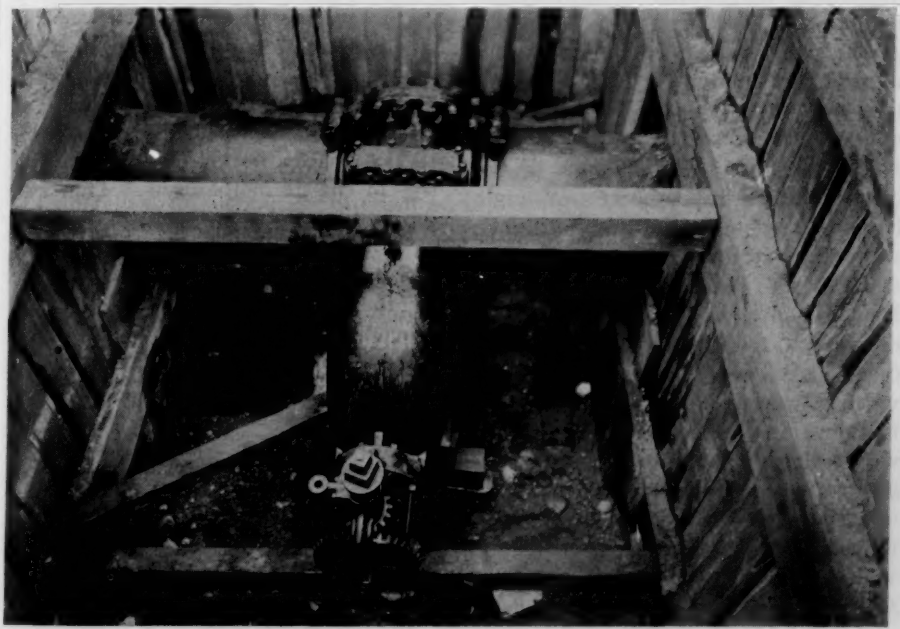

FIG. 3. First 24-Inch Gate Valve Installed, Minneapolis, 1920

During the cutting operation the cutters require a certain small clearance. This means that the newly cut ends of the pipe would protrude beyond the position desired for the seat rings of the gate. The bronze seat

FIG. 2. Double-Ended Pipe Cutter

FIG. 1. Set-up for Installation of First 24-Inch Gate Valve; showing slide valve dome

rings would therefore be made in angle form, the horizontal leg having a faced end surface and the outside circular surface threaded. The vertical leg would have gear teeth around the complete circle. Each ring would be mounted on an inward projecting rib of the gate body on circumferential threads and at this stage would be run back to clear the cutters. In adjusting these rings they would be screwed out toward the disks by means of wide-geared pinions engaging the ring teeth, the stems extending through a stuffing box to the exterior of the gate. By operating these seat rings they would finally extend inside the plane of the cut ends of pipe and the vertical angle leg would set up against the machined rib in the gate body, thus enabling the disk rings to seat against the finished bronze body rings. The slide gate dome would be attached to the body of the gate where a temporary flap valve covering the slot would be mounted. By release screws this flap would close the slot with the pressure when a vent cock at the top was opened. The dome could then be removed and the slot adequately closed with a permanent plate. The gate at this stage would thus be completed and ready for service.

Minneapolis Installation

In 1920 Mr. O'Brien announced that most of the order for eighteen of these gates had been fabricated, but that he was reluctant to send them out until the operation of insertion could be accomplished without any difficulty or mechanical interruptions. The writer was directed to go to the factory to obtain a report on progress in the fabrication and to view the set-up of a trial insertion. One length of a 24-in. pipe, closed at both ends, had been buried in a trench and placed under pressure. The insertion had been made near the center of this pipe. Due to the newly made fill and the shortness of the pipe which did not afford sufficient rigidity and alignment the first effort was not successful. A slight settlement occurred and the insertion was interrupted.

Of the eighteen gates shipped to Minneapolis, the first was installed at Harrison St. and Third Ave. S.E. in 1920. Charles Astley from the factory was in charge of the crew. This was the first gate of this type ever inserted in a regular water main.

Later, the city purchased nine more of these valves and completed the scheduled installations.

Each insertion was consummated without turning off a single section of main. There was some trouble with one insertion when some of the cutting chips washed into the groove of the slide valve causing some leakage into the excavation. By the use of lead wool, however, this was reduced so that the operation was completed in the regular way.

Much credit is due to the perfection of this novel and heretofore untried machine for its successful installation without mishap in its first group of trials.

Although the field for this appliance is somewhat limited, this carefully designed device must be considered as one of the most ingenious mechanical appurtenances contrived for use in specialized water works practice.

Cement Lining of Pipe in Place at New Albany, Ind.

By F. A. Schaefer

BEGINNING in 1932, a study of methods for overcoming tuberculation in water mains was undertaken at New Albany, Ind. This survey was conducted independently of water purification control methods, being considered as a distribution problem only. Although investigation had indicated that chemical control did at times partially control tuberculation, so many factors are involved in the quality of Ohio River water that production of a constantly stabilized water is an unattainable goal. Thus, in spite of all control efforts, tuberculation progressed with the aging of the pipe.

Flow tests over a period of years indicated that a gradual decrease in flow capacity was being experienced, so, to maintain flow in proper quantity, recourse to cleaning and lining of mains was deemed necessary. These efforts at mechanical control had previously been devoted exclusively to main cleaning, which, although an effective temporary expedient, proved to be anything but a permanent solution. It was found that each subsequent cleaning accelerated tuberculation until it returned so rapidly that in two years flows would have been decreased to pre-cleaning low capacities.

With the failure of this method of control, consideration was given to developing methods for the application of tar or asphalt preparations, and when no practicable methods of doing this suggested themselves, the use of cement linings was investigated. It was in these latter studies, particularly in the reports of success with the Tate process in England and Australia, that a permanent cure for tuberculation was seen. Pending the development of the Tate process in this country, the department adopted cement-lined pipe as a standard for new installations and, since the beginning of the war, has modified its standard to permit the use of asbestos-cement pipe.

In realization of the expense involved in lining all old mains, the department has extended its studies to include consideration of methods of treatment to control tuberculation. At present, experiments are being made with sodium hexametaphosphate, but no comments on results are justified at this writing. In preparing for observation of the results of this chemical control method, sixteen stations have been established for observation of tubercle growth.

In every instance where cement linings have been observed or where flow

A paper presented on April 30, 1943, at the Indiana Section Meeting, Indianapolis, by F. A. Schaefer, Supt., Public Service Co. of Indiana, New Albany, Ind.

tests have been made, no tuberculation has been apparent. With this experience as a guide, it was decided, in the spring of 1942, to contract for the first in-place cement lining job.

Planning and Preparation

The mechanics of operation of the Tate process are comparatively simple, yet depend on thorough planning, skilled labor, special equipment and good engineering. It is most convenient and economical to locate all main specials, valves and service taps prior to proceeding with the work. Unknown or forgotten specials and taps will be located during the processing, but may result in plugged laterals, damaged tools and will definitely slow up the work. An extra 25-per cent per unit charge is added for such missed items and very justly so. The value of maps and records is obvious under such conditions. This was especially important in the job contracted as the main was in the hard surface of a state highway and paving charges were extremely high, making every unnecessary or enlarged opening expensive.

In this connection, it should be pointed out that the contractor's engineers should give careful study to opening sizes, since the fact that the openings in the New Albany project were too large was largely responsible for increasing the paving estimate from $600 to $1500.

Valves are important to the work and, if fairly numerous and in good operating condition, will facilitate the work and reduce customer inconvenience to a minimum. Mechanical joint caps and plugs serve well where valving is inadequate. Plans of New Albany contemplated making detailed records of everything uncovered and changing of bad main and service practices encountered. Defective valves were repaired, new valves installed and some present valves relocated as the work progressed. Since the department was obligated to supply personnel for notification, turn-ons and turn-offs, chlorination and miscellaneous contacts with the customers, one department representative was present at all times. He was able to correct all drawings and to make most service rehabilitations. Good planning for a lining job includes, at the very least, the consideration of all the above items.

Briefly, the preparations for cleaning and lining consist of cutting out a main section, approximately 7 ft. long at each end of a stretch of main (usually one city block in length—maximum stretch about 700 ft.) after a 2-in. bypass line is run in the gutter and all services are disconnected from the main and connected to a bypass main with garden hose. Large services and dead-end mains are generally supplied through a 8-in. connection, either from the bypass main or from intersecting mains. Fire hydrants are cut from the system and left inactive. If abandoned taps are included on the maps and records, they are uncovered at time of preparation. After a cut is made, all corporation plugs and fittings protruding into the main are loosened and unscrewed so they will not interfere with cleaning and lining tools. All intersecting mains and large service lines are then capped or plugged and restored to service. Fire hydrant leads are left open at point of severance.

Cleaning and Lining

Three tools, in the order named, are used in cleaning the main: (1) an all-metal cutting or tubercle loosening and crushing tool; (2) the same tool with wire brush inserts instead of knives;

and (3) a train of rubber discs. Special winches geared for several speeds pull the flexible wire cable with tools attached. These winches are mounted on trucks and one truck is placed at each end of the section to be cleaned, cleaning being carried on alternately from each end. The number of cleaning operations with each tool varies with the condition of the main. When the rubber discs finally come through, bringing no sediment or water, the main is ready to be lined. The lining process then follows immediately.

A cement and sand mixture is prepared according to Tate specifications and is placed in the main. About 20 per cent more lining material than needed is used. A self-centering lining tool is inserted and pulled very slowly through the main in one direction only. This tool is designed to place the same thickness of lining on the entire inside surface and, at the same time, to dehydrate the cement so it will remain in place without sagging. Back pressure on the tool is supplied by the cement it is pushing ahead of it. As the quantity in front of the tool decreases toward the end of the operation, pressure is supplied by blocking the exit point sufficiently to create the necessary back pressure. The time to line a section (up to 700 ft.) is approximately 20 min. The finished lining is approximately $\frac{3}{16}$ in. thick except in the bottom of the main where it is thicker and flat, due to the excess cement placed at this point through the colander-like holes in the lining tool that produce the desired dehydration.

As noted above, the actual lining operation takes but little time; preparation and re-establishing services are the elements requiring the time-consuming operations. Re-establishment of the service begins immediately after lining. Corporation cocks, etc., are removed, the cement cleaned from them and then replaced permanently in the main. The cut-out sections of mains and larger services are lined by hand and replaced. Chlorination follows and, after allowing a "setting" period of 24 hours, plus or minus, depending on outside temperature, etc., the services are removed from the bypass and restored to the main, following which operation moves on to the next section.

All this requires skilled and careful labor. Observation of the contractor's mechanics and laborers on the job indicated that they were trained almost to perfection. Cleanliness was emphasized, even to the extent of spotless cleaning of the men's boots before they entered the concrete mixing box. Thoroughness in cleaning operations was particularly apparent in the fact that the last squeegee operation produced no sediment or water.

Special equipment originated and designed by the developers of the process was used in practically every process. The engineers accomplished the job with a minimum of suggestion from the local superintendent and a maximum of favorable customer reaction as complaints were practically non-existent. Full advantage was taken of the speed and economy of mechanical joints.

Cost of Project

Table 1 attempts to show clearly the various factors involved in the process and their relationship to total cost. The cost of conventional main cleaning methods is about one-third the total given in the table, but cleaning costs are recurrent, whereas it is believed that the cement linings will permanently stabilize the capacity of the main.

This first project at New Albany was especially expensive at it was in a congested downtown area and all work was done under concrete and asphalt, with concrete base paving. It is estimated that a project of lining 632 ft. of 10-in. and 6938 ft. of 6-in. pipe, proposed for 1943, will cost only 92.26 cents per foot.

Results Achieved

The principal purpose of the New Albany lining program is to insure permanency of flow capacity after cleaning. According to tests made at other locations, cement lining has resulted in definite improvement in friction coefficients. No such tests were

TABLE 1

Cost Analysis for Cleaning and Lining Contract on New Albany, Ind., Project

Pipe—8-in.	4271 ft.	@	$ 0.76	$3245.96	
—6-in.	1365 ft.	@	0.70	955.50	
—4-in.	48 ft.	@	0.65	31.20	
Fittings—10-in.	1	@	12.00	12.00	
Tees—8-in.	6	@	14.50	87.00	
—6-in.	6	@	13.00	78.00	
Crosses—8-in.	10	@	24.50	245.00	
—6-in.	2	@	21.50	43.00	
Reducers—8-in.	3	@	12.00	36.00	
6-in.	6	@	10.50	63.00	
Bends—4-in.	4	@	9.50	38.00	
Valves—8-in.	9	@	14.50	130.50	
—6-in.	7½	@	13.00	97.50	
—4-in.	3	@	11.50	34.50	$5097.16
Services Disconnected (Regular)—2-in. and over	8	@	4.00	32.00	
—Under 2-in.	167	@	3.00	501.00	
Services on Service Taps Disconnected (Found During Cleaning Process)—2-in. and over	1	@	5.00	5.00	
—Under 2-in.	14	@	3.75	52.50	
Bypass Line Installed—2-in.	4840 ft.	@	0.03	145.20	
Extra Trenching Charges—Cover Beyond 4½ ft.	360 ft.	@	0.05	18.00	753.70
Subtotal (Cost per foot $1.0294)					5850.86
Paving Costs—City Inspection	54¾ hr.	@	0.75	41.06	
—State Permit (152 holes)	2634.15 sq.ft.			1447.90	
Subtotal (Cost per foot $0.2620)				1488.96	
Company Labor (Cost per foot $0.0208)	167 hr.	@	—	118.04	1607.00
Total (Cost per foot $1.3120)					$7457.86

made for this project. The flow test data in Table 2 are based on the standard flow tests of the Indiana Inspection Bureau and the National Board of Fire Underwriters, which presuppose that all mains have a coefficient of 90.

Viewing the before and after results in this table, the tests made before cleaning should no doubt be figured on a lower coefficient and those made after cleaning and lining, on a higher coefficient. In Table 2, it will be noted that "cleaning only" gave a great increase in flows, but it should also be noted that lining indicates an improved condition in spite of an internal diameter reduction.

In conclusion it should be pointed out that the New Albany Water Department considers its experience with this method of in-place cement lining of pipe entirely satisfactory, for several reasons:

1. It is at present a most successful cure for tuberculation in old mains.
2. It has the advantage of permanence.
3. The costs, although high, are not recurring.
4. The results in increased flow capacities are greater than can be obtained by any other means, except the installation of larger mains.
5. The mechanics of the operation are not a major inconvenience to the consumers.

TABLE 2

Flow Test Data Before and After Cleaning and Lining

Location	Flow, in gpm.*				Pressure, in psi.								Location of Pressure Station
					Static*				Residual*				
	A	B	C	D	A	B	C	D	A	B	C	D	
13th & Market	750	850	930	1000	58	55	65	64	26	31	38	43	14th & Market
13th & Main	610	665	750	770	57	53	66	64	35	35	47	45	13th & Market
14th & Main	520	640	690	750	58	54	67	65	37	35	45	48	13th & Main
15th & Main	560	710	810	790	58	56	65	65	31	32	39	43	14th & Main
15th & Dewey	490	665	700	700	61	54	65	66	36	35	42	42	15th & Main

* A: Test made before cleaning; B: test made after cleaning (peak load); C: test made after cleaning (light load); D: test made after cleaning and lining.

Installation of Water Meters

By John L. Ford

UPON the correct installation of a water meter depends, to a large extent, the satisfaction and service it renders the utility and the favorable impression it makes on the customer. So it behooves every water works to follow the rules of good practice in putting in its meters. A water meter in a service line should be well protected and as easily available for reading and changing as is economically practicable. A properly installed curb meter is at the logical point for metering, i.e., at the beginning of customer's service. Meter reading and changing are independent of the customer's presence or whims. Curb meters can, ordinarily, be read much more quickly.

In cold climates, where outside settings must be deep, large and consequently expensive, economy sometimes dictates basement settings. Heavy and enduring snows can make reading of outside meters slow and difficult, or piping and other conditions can favor inside settings. Location of water meters is a separate problem for each water utility, even for each service and, therefore, merits careful consideration.

A portion of the Indiana Section Technical Committee report for 1941–42 by John L. Ford, Chairman of the Subcommittee on Meter Settings, Secy.-Treas., Ford Meter Box Co., Wabash, Ind.

Basement Meter Settings

A basement meter setting is the link between two distribution systems—that of the water works and that of the customer. It is the point where the water works delivers and the customer takes over. As such it deserves special consideration in the maintenance of customer-utility relationship. In general, water meters in basements should be in as clean, protected and available a location as possible, safe from freezing and mechanical damage. They should be from one to three feet above the floor, set level, with the dial up. A good valve should be used at the meter inlet and an outlet valve is also valuable to the utility and to the customer. If the basement is not frost-proof, the meter should be set outside, as the cost of repairing a badly frozen meter may be more than the cost of a safe meter box.

The Fire Underwriters' 1940 National Electrical Code * (Sec. 2612a) specifies that: "If the point of attachment [of electrical connections] is not on the street side of the water meter,

* *1940 National Electrical Code.* Standard of the National Board of Fire Underwriters for Electric Wiring and Apparatus as recommended by the National Fire Protection Assn. Approved by Am. Standards Assn. NBFU Pamphlet No. 70 (November 1940).

the water piping system shall be made electrically continuous by bonding together all parts between the attachment and the pipe entrance which are liable to become disconnected, as at meters. . . ."

Pit Meter Settings

1. A good meter setting is a safe setting, safe for the meter and safe for pedestrians. A meter box or cover which locks securely and which is designed to provide required frost protection should be used.

2. It should be remembered that freezing of meter settings results from one or more of the three following causes: too shallow a setting so that frost penetrates to the bottom; too small a setting so that there is not enough clearance between the walls of the box and the risers; and a design of the top of the setting which gives too much exposure or heat leakage.

3. A meter vault must be deep enough to extend below the deepest frost line. It does not pay to be skimpy in depth of services or meter settings; several inches of safety should be allowed beyond the deepest frost penetration. One or more courses of brick can be laid below the meter box barrel to provide greater depth as well as to give a foundation for the setting.

4. Meter box tile or barrels large enough to provide sufficient clearance for the riser pipes should be used in those settings where the meter is brought up in the box. Vitrified clay provides the best insulation, concrete next and iron least. As a general rule it is well to use tile not less than 18 in. in diameter for settings 36 in. or more deep and not less than 20 in. in diameter for settings 54 in. or more deep. For extremely cold climates larger tile may be necessary.

5. Soil should be filled in firmly around the setting, tamping clear to the top. If available, this filling should be clay or loam, as either is much better insulation than gravel, sand or cinders. With soil of poor insulating qualities, greater care should be taken to have riser pipes centered in the tile or larger meter box barrels should be used to provide greater clearances. No fill should be used inside the tile.

6. Although not absolutely necessary, a well designed meter-holding device is a great advantage in a meter setting, in that it insures easier and trouble-free meter changes, holding inlet and outlet piping physically connected when the meter is removed. A valve at the meter inlet, which can be included in meter holding devices, is a great convenience as well as a saving over the ordinary valve and curb box. A test valve at the outlet may be included.

Freezing of Pit Meters

Heat always moves from the point of higher temperature to the point of lower temperature. When a meter in a pit freezes it does so because the warmth inside the box is lost to the cold surroundings at the sides and top of the setting. Meters in pits freeze because cold enters the setting for one or more of the three following reasons:

1. The setting is so shallow that the ground freezes clear down to the bottom, so that the floor of the pit can no longer radiate warmth up into the interior.

Remedy: The meter setting should be deepened to well below the deepest frost line.

2. The setting is so proportioned or installed that one or both of the riser pipes contact the wall of the box above the frost line or come so close to it

that frost bridges the gap, freezes the pipe and then the meter.

Remedy: The risers should be centered in the box or tile, being sure that there is clearance. When frost penetrates frequently to the level of the riser tops, a tile or box which will provide 2 in. or more clearance should be used. This would call for an 18-in. tile for a ⅝-in. meter. A meter pit over 4 ft. deep might well use 20-in. tile for ⅝-in. settings. A tapering tile is an advantage in that it provides a large floor area and a small exposure at the top, but it is more difficult to make.

3. The design of the cover or top of the setting is such that there is too great an exposure to the cold air, or there is a leakage of cold air into the box through the joint at the rim of the cover, through poorly fitting lid joints, through keyholes, etc.

Remedy: For freezing climates, the hat-shaped cover is much better than the flat cover. The top lid should be no larger than necessary for meter reading and changing. Lids should fit as closely as practical. Where zero weather is at all common, the double-lid cover should be used to cut down the heat loss as much as possible.

Water Works Improvements at Aurora, Ill.

By Carl Duy

THE history of the Aurora, Ill., Water Works dates back to the early part of the year 1886, at which time the source of supply was the Fox River. The records show that water was obtained through an infiltration gallery constructed of stone and lumber on the island just west of the present Aurora Avenue Pumping Station.

Many private wells were in use throughout the community at the time of the installation of the municipal supply system. Because of the use of unfiltered and untreated river water throughout the system, connections by domestic consumers were few and far between, but continued use of the private well supplies was in favor. The municipal system, however, provided the city with a much needed means of fire protection and an adequate industrial water supply.

Because of the inadequate quantity of water for domestic use provided by the system, it was later decided to abandon the river supply in favor of deep artesian wells. Subsequently, in March 1891, the city drilled Well No. 1, which was completed at a depth of 1338 ft. Construction of Well No. 2 was completed in 1892 and of Well No. 3, in 1893, to depths of approximately 2250 ft. Well No. 2 was later drilled to a depth of 2700 ft., the first well of this depth to be drilled in this part of the country. At this depth, however, excessive amounts of salt water were encountered, so the lower 450 ft. of the well were plugged to shut off the flow of water containing objectionable salts. Thereafter, Well No. 1 was also drilled to a depth of 2250 ft., which has been the standard depth of all wells that are in operation at the present time. These first three wells were abandoned several years ago.

Present Status of System

The water supply at the present time is derived from ten deep wells, nine of which receive the majority of their water from the Mt. Simon sandstone. Total production is approximately 11 mgd. Six of these wells are located at various points throughout the system and pump and deliver directly into the distribution system. The remaining four wells, located at the main pumping station on Aurora Avenue, about two miles north of town, deliver their water into two surface reservoirs, one having a capacity of 1½ mil.gal. and the other of 4 mil.gal.

In 1936, a new electric booster station was constructed at the Aurora Avenue Pumping Station. The maximum capacity from this main station to the distribution system is 17 mgd.

A paper presented on April 8, 1943, at the Illinois Section Meeting, Springfield, Ill., by Carl Duy, Engr. of Water Works, Aurora, Ill.

The unit consists of three electric-motor-driven and two gas-engine-driven booster pumps, the gas engine operating on natural gas supplied by the local gas utility company. The four deep wells at the main station have a production capacity of 7 mgd.

The municipal distribution system contains approximately 150 miles of water mains, ranging in size from 4 to 16 in. in diameter. At the time the new booster station was built, additional mains were installed from the main central plant around the outside of the populated area that feeds to the gridiron system and to a new 1½-mil.gal. elevated storage tank located in the southeast part of town, to give a more balanced operating condition.

The system serves the city's average population of 52,000, through approximately 12,000 consumer connections with about 6 mgd. for normal consumption and 4 mgd. for minimum consumption. No records of peak load were available, but on the basis of 1941 records, it was determined to be approximately 9 mgd.

Improvement Program

In May 1941, the author was appointed to manage the system and has since been in charge. One of the first activities undertaken under his management was a three-point program of investigation: (1) to determine the maximum capacity of the plant; (2) to determine the normal and maximum demand requirements of the consumers; and (3) to determine how much of the water pumped into the system was actually accounted for.

According to the records, the amount of water unaccounted for reached the staggering figure of 48 per cent of total pumpage, i.e., *only 52 per cent* of the water pumped was *accounted for.*

The entire system—domestic and industrial—is metered, the only services *not* metered being those of the pumping stations, municipal buildings, playgrounds, city parks and the city golf course, together with those providing the water used for fire protection by the City Fire Department.

One of the first steps taken to determine whether the large ratio of unaccounted-for water was correct was to test each well for its capacity and drawdown, to arrive at the specific gallons per foot of drawdown in each well and to determine the power consumed. This investigation was made at the outlying wells which pumped directly into the system. The results showed that the recorded kilowatt cost per million gallons on three of the wells was lower than the average wire-to-water efficiency that it was possible to obtain from modern deep well turbine pumps. Also, the recorded figure of specific gallons per foot of drawdown indicated that the well was in a better productive capacity than actually existed. Therefore, the master turbine type meters in each station were removed and sent to the respective manufacturers for overhauling and repair. Upon their return for re-installation it was proved that they had averaged from 75 to 275 gpm. fast. Additional tests then made indicated that the meters had been restored to normal accuracy, at least temporarily.

A careful record system was then established to provide a monthly report to the main office of all water used for hydrant flushing and for fire fighting. Next, all hospitals and playgrounds receiving free water were requested to remove all their inactive meters and deliver them to the meter shop for repair and re-installation for metering requirements.

One of the largest consumers unaccounted for was the city park, which accommodates an 18-hole golf course, two large lagoons and a small swimming pool for children. All these services were provided with up-to-date meters, so that, at the present time, there is an accurate check on the amount of water required at each location. It is believed that this step has eliminated a great deal of water waste. These meters are read monthly (as against quarterly readings of domestic meters) and accurate consumption records are kept.

In 1942, a rather unusual situation was encountered in this phase of the work. Load requirements started to increase gradually at a season when the increase was not warranted. All efforts to determine the cause were of no avail. Finally, however, it was found that one of the 12-in. mains from the main plant had been leaking into a manhole for about 30 days, after which time it burst, blowing out a section of pipe about 6 ft. long. This main had had a storm sewer manhole built on top of it. When the repair was made, it was definitely ascertained that the manhole had no connection with the water main.

Another step taken to determine whether the large ratio of unaccounted-for water was correct was an inventory of every meter on the system, to record size, make and serial number and to determine how many consumers, if any, were receiving water unmetered, with no record of account. It was surprising to find that a number of such unmetered services existed. Each meter reader was instructed to report every house number on his route at which no meter was read. The office then checked with the records to see if these houses were metered through the adjoining property. If they were not, arrangements were made for the installation of a meter.

Having taken this inventory of all meters and knowing their serial numbers, the management obtained from the manufacturers a complete record of the ages of the meters, which revealed the necessity for retiring a number of them.

In connection with this investigation, all industrial and mercantile buildings equipped with sprinkler systems were checked to determine the number of sprinkler heads in service. This survey indicated that previous records had allowed a large percentage of these buildings to pay for a much *lower* ratio of heads than actually served.

During the last year of operation a careful control was maintained to determine actual water loss. For the year, it is known that 40 per cent of pumpage is still unaccounted for. To bring this amount down to the proper percentage, an investigation is contemplated this spring, to survey the entire gridiron system, as well as large consumer meters, to determine just where the losses exist.

Investigation of Wells

In the early part of 1941, the well investigation was continued, studies being made of their construction and of maximum possible production. These tests indicated which wells needed most immediate attention.

In the testing of Well No. 11, drilled in 1928 to a depth of 2250 ft. and having an 18-in. top and a 16-in. bottom, it was found that capacity had decreased considerably. In 1928, the well was capable of producing 1200 gpm. at an operating level of about 345 ft., but, over the five-year period since then, it has been delivering only about 800 gpm. at a 355-ft. pumping level.

The recovery period of the well, after operating for a given time, was very long, indicating the presence of a bridge through an uncased portion of the well. Operating under these conditions, pumping cost was high, inasmuch as the turbine pump had to be throttled to a capacity equal to the production capacity of the well. To correct this condition, the well was sounded, revealing the presence of several bridges that retarded the flow. After these bridges had been cleaned out, the well was shot with 250 quarts of nitroglycerin, each shot ranging from 30 to 60 quarts and placed at intervals of 50 ft. in the Mt. Simon sandstone. Upon completion of the shooting, approximately 75 cu.yd. of Mt. Simon sandstone was bailed out of the well. To eliminate further caving, a liner was installed from the 1300- to the 1700-ft. level, in the Eau Claire sandstone.

The casing was slotted (about 75 per cent of its linear length) so that the slotted opening was equal to ten times the area of the opening of the pipe. The casing was supported in the well, at the bottom of the 1700-ft. elevation, by means of a hook-wall packer. Upon completion of the reconstruction, a test was made over a continuous period of 65 hr. The tests run prior to the rehabilitation showed the well to be capable of delivering 4 gal. of water per foot of drawdown, whereas, after completion of the reconstruction, the well delivered 10¼ gal. per foot of drawdown.

Three other wells in this locality, ranging from 1400 to 3000 ft. apart were also used in the testing program. First, Well No. 11 was run by itself, with these other wells shut down; then it was run with the other three wells operating in parallel; and finally, with all wells operating at the same time. The tests showed that, with a pumping rate of 4500 gpm., a 17-ft. greater drawdown and a slight decrease in specific capacity resulted. After the well was put into operation, in May 1942, and had been operating for 60 days, the production increased to a present yield of approximately 13 gal. per foot of drawdown.

The cost of rehabilitating this well was approximately $7500, but in the first eight months of operation power savings amounted to approximately $2000. From the results of the tests, it is estimated that, in a twelve-month period, this well will show a minimum saving of $3000.

Upon completion of the work on Well No. 11, provisions were made to rehabilitate Well No. 9, in which capacity had decreased from 1000 to about 650 gpm. On this rehabilitation project also, a cave-in in the Eau Claire sandstone was experienced. After cleaning, the well was shot with 250 quarts of nitroglycerin and considerable amounts of Mt. Simon sandstone were bailed out. At the time of writing (April 1943) the size casing to be installed is being determined upon the basis of an electric logging of the well by the State Geological Survey. It is anticipated that returns similar to those of Well No. 11 will be obtained as a result of the reconstruction.

Well Equipment Deterioration

In 1935, a new well, Well No. 12A, was drilled to the east of the main pumping plant. This well takes its water from the same sandstone as Wells No. 11 and No. 12. After the turbine pump in this well had been operated for a 24-month period, however, the drop pipe and other parts of the lower

section of the installation deteriorated. Each time it was removed from the well it was repaired and put back into operation. When the pump was removed from service in 1942, a careful inspection revealed that the metal showed signs of electrolysis. The protecting pipe surrounding the shaft from a point 160 ft. below grade—static level—down to the top of the pump proper, at an elevation of 350 ft., was in bad shape and the entire line shafting looked just like a coarse file.

It was thought that the Chicago, Aurora & Elgin Railway, which passes within about 1600 ft. of this plant, was probably causing strayed current losses in the metal equipment. To check the accuracy of this assumption arrangements were made to connect the third rail (power line) of the railway to the well casing and to install 24-hour recording charts on the hook-up. This survey, however, proved unfruitful of any solution of the problem.

A further attempt to solve the problem of this deterioration was made in the reinstallation of this pump by bonding the cast-iron pump bowls to the steel drop pipe with copper plating from the bottom of the installation. At the top, a bond was made between the steel drop pipe and the cast-iron discharge head, with proper arrangements for grounding. Just what results will be obtained from this experiment is not yet possible of determination. The method was applied after extensive consultation with engineers familiar with problems of this kind. The pressing need to correct this condition is indicated clearly by the fact that the cost of removing and repairing this pump (including labor and material) every two years amounts to between $2500 and $2800.

Other Improvements

At the present time the department is somewhat at a standstill in its program of revamping its wells because of the war-created scarcity of materials. Many of the wells are greatly in need of rehabilitation and three of the turbine pumps now in operation were designed as long as 25 years ago. The installation of modern turbines, designed for the capacity of the well, would undoubtedly result in a considerable power saving.

Such minor details, as redecorating all pumphouses and providing wells in the outlying residential districts with the proper galvanized fencing are taken care of in the normal course of operation.

To provide a better control of the purchasing and stocking of equipment an inventory system was established for the entire system. This system has made it convenient to determine just what equipment is available for immediate use in the event of trouble and has made it possible to eliminate overstocking or understocking of various materials and, thus, to maintain a balanced inventory.

With the existing system of maps and drawings it was rather difficult to obtain immediate information on the gridiron system as a basis for making quick decisions in emergencies. Therefore, the city was divided into sections and a complete set of maps was made for each, showing the size of the main, the length in each block, the sizes and types of fittings and the sizes and types of hydrants. As a part of this project, a complete inventory of the number, makes and sizes of all hydrants was made as a basis for further control of spare parts requirements. The records thus obtained made it pos-

sible to provide for any emergency demand on this equipment.

Before any revamping or reconstruction of the reservoirs, pumping stations or pipelines was undertaken, the State Department of Public Health was invited to inspect the entire plant and system. Upon receipt of its report, corrections were made in existing equipment and plans were made to incorporate all recommendations in all future reconstruction and new construction.

Engineers of the National Board of Fire Underwriters were also consulted for their viewpoint on projected reconstruction or expansion. It was hoped in this way to eliminate any unnecessary items and to key reconstruction and expansion activities to the purpose of reducing insurance rates.

An investigation of the meter shop indicated that the records of costs and charges on new and repaired meters were rather limited and that testing methods were rather antiquated. Therefore, new calibrated testing tanks were installed, with the purpose of providing better control of repaired meters. Also, with the co-operation of the meter shop, a card system was installed in the office making a record of the date, nature and cost of repairs of each meter, so that if any complaint was received, it could definitely be determined whether the consumer was justified in his complaint and whether he had any adjustment due. It should be pointed out that the *consumer* purchases and owns the meters and pays for their repair and maintenance. All repairs, however, are done in the department meter shop.

To be able to serve the consumer better and more rapidly and to co-operate with him at times when he considers his bill too high, a portable calibrated test tank was purchased for in-place checking of the accuracy of meters in consumers' installations. This system is now about to be put into operation.

To improve the financial status of the department, an effort was made to reduce the accounts receivable by an aggressive follow-up of all delinquencies. This drive resulted in reducing the accounts receivable by 55 per cent.

Operation Controls

For further control of operations a definite policy of weekly well testing was established during the past year, whereby, on Monday and Tuesday of each week, each well is tested for power consumption, static water level and specific capacity. This operation will, no doubt, make possible maintenance economies as the tests indicate that some of the operating water levels are such that the pumps have no margin of submergence. These conditions are being corrected at the present time.

To give a more complete picture of well construction, a composite graph showing U.S.G.S. elevations, static levels, casing levels and Mt. Simon levels has just been completed. This graph makes available in one record complete information on all wells. Complete chemical analyses of the water from each well are also being made and compared with those of many years ago, but no discussion of these comparisons can be made as yet.

The author wishes to acknowledge the assistance and co-operation of the Honorable A. J. Carter, Mayor of Aurora, of the Water and Light Committee, the City Council and of members of the Water Department, in making the above-described accomplishments possible.

Design and Operation of Woodlawn Softening Plant

By E. V. Grimshaw and E. F. Twomey

THE Woodlawn Water Company serves the major portion of the Borough of Aliquippa, Pa., a municipality of approximately 30,000 population, located on the west bank of the Ohio River, approximately twenty miles downstream from Pittsburgh. The community is essentially industrial and is the home of the Jones and Laughlin Steel Corp., which is supplied with drinking water and a small portion of its process water.

History of Water Company

The Woodlawn Water Co. was chartered in 1907 and was at that time intended to serve the drinking water supply for the mills of the Jones and Laughlin Steel Corp. and a few adjacent company-owned houses. The entire river front of the borough is occupied by corporation property.

From 1907 to 1930, a small area on the river bank, approximately 1000 ft. long and 150 ft. wide, was utilized as a well field, five separate developments being constructed in this limited space. Over the 33-year period, 22 wells were constructed in this area and were connected to a central pumphouse by means of five separate suction lines laid substantially at the level of the normal pool of the Ohio River. All of the wells were operated with a low drawdown limited by the vacuum lift of the centrifugal high-lift pumps which furnish water to the distribution system.

The original development constructed in 1907 consisted of three 6-in. wells with the lower 20 ft. of the casings slotted. The wells were spaced approximately 100 ft. apart.

The first addition to the well supply was made in 1909, comprising three 6-in. units, spaced approximately 150 ft. apart. At this time, the population served was approximately 1400 persons in addition to the normal mill consumption. By 1916, there had been a substantial increase in industrial activity, so that another group of three 6-in. wells was constructed within 500 ft. of the central pumping station.

In 1923, the capacities of the existing wells were again exceeded and there was indication of excessive iron and manganese production from some of the units as well as a decrease in the capacity of the group of wells. At this time the population served exceeded 13,000 and the industrial use of water amounted to approximately 500,000 gpd. During the year, two lines, each with five 10-in. wells spaced 100 ft.

A revision of a paper presented on September 18, 1942, at the Western Pennsylvania Section Meeting, Pittsburgh, by E. V. Grimshaw, Asst. Supt., Woodlawn Water Co., Aliquippa, Pa., and E. F. Twomey, Cons. Engr., Morris Knowles, Inc., Engineers, Pittsburgh.

apart, were constructed immediately adjacent to the river bank and connected to the central pumping station by two 12-in. suction lines. These latter ten wells constituted the principal supply of the Woodlawn Water Co. from 1923 until 1939.

In general, these wells showed individual test capacities of 250 gpm. each, with a drawdown of approximately 8 ft. In the early years, the water had a hardness varying from 250 to 350 ppm., with an annual average of 275 ppm. At the time of construction, the water was relatively free from objectionable amounts of iron and manganese. In normal operation, the capacity of the individual wells was limited by the vacuum on the high-lift centrifugal pumps and the yield from the individual units varied with the distance from the main pumping unit. Investigation revealed that, as the wells increased with age, there was a moderate increase in iron and manganese content and a slight falling off in capacity, accompanied by an increase in hardness, until at the end of 1937 the quality of the water was considered somewhat substandard. The amount of iron generally varied from 0.20 to 0.40 ppm., while the manganese varied from 0.20 to 0.60 ppm. Practically all consumer complaints at this time were complaints of "red" or "black" water, little attention being paid to the hardness of the supply.

In 1928, the demands of industry for clear cold water increased and led to the construction of a gravel-packed well outside of the well field above described. This unit was located approximately 400 ft. from the river bank, penetrating 40 ft. of slag fill, approximately 25 ft. of more or less impervious sand and clay formations and 25 ft. of sand and gravel water-bearing formation, similar to that encountered at the river bank. The well tested at a rate of 900 gpm. Over a period of years the water at this location showed a hardness of 450–700 ppm. Because of this high hardness, the well was used sparingly and only at times of peak demand, generally to supply industrial consumption in the mill area in which it was located.

From 1935 to 1938, the number of consumer complaints due to iron and manganese showed a substantial increase. The general average of the combined iron and manganese during this period was 0.60 to 0.70 ppm. Consideration was given to the development of an increased ground-water supply, based upon large-diameter wells, with the expectation that such wells would have a life of not less than fifteen years and that the water would be hard and would eventually require treatment for the removal of iron and manganese and possibly require softening.

Investigations for New Supply

In the first stages of the investigation for an increased supply, an attempt was made to rejuvenate the ten 10-in. wells drilled in 1923 by cleaning them with acid and air. With the available pumping system, the capacity of these wells was increased from 100 to 125 gpm. at the limited available drawdown. This increase, however, was insufficient to provide for future requirements.

In the second stage of the investigation, test holes were drilled in the original well field to determine the economy of large-diameter wells. Holes drilled in the vicinity of the existing operating wells showed that some sand and gravel water-bearing formations were badly discolored with

iron and manganese, particularly in the circle of influence of each well, while the more remote areas were relatively clean. During the time that this investigation was being made, the gravel-packed well, which was the only available standby for peak industrial consumption, started to produce water with an iron content of 16 ppm. Investigation revealed that seepage from the slag fill had eaten through the outer casing of the well and had permitted a direct pollution of the ground water at this point. The abandonment of this large-capacity unit made it necessary to discontinue further explorations in the old well field.

Investigations were renewed at a site approximately half a mile downstream in an area on the river bank overlaid by approximately 40 ft. of slag and miscellaneous fill. A series of test holes indicated that water of the desired quantity was available only within a narrow shelf adjacent to the river bank and that the quantity of water from a given well decreased rapidly with the increase in distance from the river. Test holes further indicated that there was a substantial increase in iron and manganese as the distance from the river increased. Dry holes were encountered approximately 500 ft. from the river and those which did produce water in satisfactory amounts showed a hardness varying from 500 to 700 ppm., iron in excess of 1 ppm. and manganese in excess of 2 ppm.

New Well Supply

The wells finally constructed were 16 in. in diameter with a 24-in. outer casing carried through the slag fill and sealed in clay. The annular space between the 24-in. casing and the 16-in. casing was filled with cement grout. Each well was equipped with a 16-in. bronze screen and turbine type well pumping unit. Tests of the individual wells showed yields varying from 350 to 750 gpm. at a maximum drawdown of 17 ft., which level was sufficient to maintain 5 ft. of water above the top of the water-bearing sand and gravel. In general, such coverage of the water-bearing strata is desirable to prevent the deposition of iron and manganese in the sand immediately adjacent to the wells.

The major differences in quality of water in the individual wells are worthy of comment. The first well in the new well field showed a hardness of 290 ppm. at the time of the initial test, immediately after drilling. After a few months of pumping to waste, the hardness increased to 340 ppm. and gradually assumed the anticipated annual cycle of hardness varying from 240 to 300 ppm. During the following three years, this well showed only traces of iron and manganese.

The second well in the new field, located 350 ft. from the first well, showed an initial test hardness of 360 ppm. After two months of pumping, the hardness increased to 564 ppm. and reduced gradually, over the succeeding four months, to 320 ppm. Thereafter, it followed the normal cycle of hardness typical of the true ground-water supply of this area. This well too showed substantially no iron or manganese over a period of three years.

The third unit showed an initial test hardness of 474 ppm. which it maintained for several months before dropping to 300 ppm. This well contained approximately 0.60 ppm. iron and 0.80 ppm. manganese and therefore water from this well could not be delivered to consumers without treatment.

The fourth well showed a somewhat smaller production than the others and had considerable amounts of iron and manganese.

The fifth well, located approximately 400 ft. from the river bank, showed an initial test hardness of 550 ppm. and, over a period of several months, the hardness remained 570 ppm. This well also contained excessive amounts of iron and manganese.

The sixth and seventh wells were drilled at the top of the river bank in the old well field. The production from these wells was normal, but the iron and manganese were slightly higher than would be acceptable for domestic service without treatment.

The data regarding the initial quality of the water from the various wells have been cited to show the substantial variations in hardness, iron and manganese content in relatively short distances along the river bank. Particularly to be noted are the extreme variations in the quality of water obtained from the ground sources at small distances from the river, as well as the effect of the superimposed slag fill and the time necessary to clear the pollution accumulated in the more or less impervious sand and clay formations located immediately above the water-bearing sand and gravel formations.

On July 25, 1939, the first two wells in the new well field were connected to the distribution system. From that time until March 17, 1942, these units, with a total capacity of 1050 gpm. supplied the community with water for domestic purposes. The water so supplied had an average hardness of 275 ppm. with a combined iron and manganese content of less than 0.30 ppm. During this same period, the wells built in 1923 were continued in service to supply the industrial requirements of the steel mill.

The total installed capacity of the new wells is 2900 gpm. In general, five units, having a combined capacity of 2175 gpm., are sufficient to supply the ordinary demands upon the system.

Except for short periods, the hardness of the raw water has varied between 250 and 400 ppm., while the iron and manganese content have varied seasonally from 0.10 to as much as 1.0 ppm., depending upon the combination of wells used.

Samples of the raw water taken over a period of time have shown that the untreated water generally has complied with present-day bacteriological requirements for drinking water.

In 1940, the increased demand for both domestic and industrial water made it necessary to consider the utilization of additional wells with higher hardness and objectionable amounts of iron and manganese. This, in turn, made necessary the treatment of the water for the removal of the objectionable constituents and eventually the softening of the entire supply. It should be pointed out that there was no apparent demand on the part of the consumers for softening, but a rather widespread dissatisfaction because of the objectionable amount of iron and manganese. A survey of the consumers indicated that they were willing to pay substantially higher rates for soft water. This led to the initiation of the zeolite softening project.

Design of Softening Plant

The softening plant has been designed to produce 2000 gpm. of finished water having a hardness of 75 ppm. when the hardness of the raw water is 412 ppm. It is expected that, for a few years, the average hardness

will be materially less than this figure and that the capacity of the plant under these conditions will be 2500 gpm. or 3.6 mgd.

The treatment plant is located outside the industrial property, approximately a mile from the well field. The starting and stopping of the individual wells is controlled by an automatic telephone circuit located at the treatment plant. The control equipment is arranged so that the operator may select the individual well which he wishes to put on the line, may listen to the motor on the well pump as it comes up to speed and may listen to the operation of the motors at any time during the operating period. This arrangement has eliminated the necessity for attendance at the well field, except for routine inspection for mechanical condition.

The plant is designed to soften the major portion of the water to zero hardness by passage through natural greensand zeolite. Depending upon the hardness of the water, the amount softened to zero varies from 60 to 80 per cent of the total and is regulated by adjustment of the controllers on the individual units. Operations are controlled so that the softening units are taken out of service for washing and regeneration at the end of each period of zero hardness production. Units have not been operated in the so-called twilight zone.

The make-up water necessary to produce a finished water with a hardness of 75 ppm. is treated with lime. The normal pH of the raw water varies from 7.1 to 7.4. The pH of the make-up water is raised from 9.6 to 10.0 to precipitate the iron and manganese present in the raw water. This range of pH is generally sufficient to remove all iron and manganese in the settling basin and to raise the pH of the zeolite-softened water to 8.0.

The zeolite-softened water and the filtered hard water make-up are mixed by means of baffles to produce a finished water of the desired hardness.

The major portion of the water to be softened is pumped directly from the wells to six zeolite units, each 14 ft. by 18 ft. in plan, with a greensand layer 38 in. deep. Each unit contains 800 cu.ft. of greensand of a guaranteed exchange capacity of 3100 grains per cu.ft. This value has been exceeded in actual operation and results generally have fallen within the range of 3300–3500 grains per cu.ft.

The greensand is supported by four grades of gravel, each 2 in. in thickness: the lower grade ranges from $\frac{3}{8}$ to $\frac{5}{8}$ in.; the next grade, $\frac{1}{8}$ to $\frac{3}{8}$ in.; the third, $\frac{1}{32}$ to $\frac{1}{8}$ in.; and the final grade, torpedo sand with the largest particle $\frac{1}{32}$ in. The underdrainage system is of "Leopold" concrete duplex filter blocks made at the site of the project.

The normal rate of operation of the zeolite filters is 2 gpm. per sq.ft., although, in general, it has been found desirable to alter the rate of flow to correspond with the desired total output of soft water for the given conditions of hardness in the raw water.

Each unit is controlled by hydraulic valves operated from a central control table on which are mounted the loss-of-head and rate-of-flow gages and the various control handles for the functions of the unit, including brining and rinsing.

Each unit is equipped with a perforated cast-iron header for the application of brine immediately above the zeolite. The salt solution is applied by a pump controlled either at the main switchboard or at the operating table in the filter operating room.

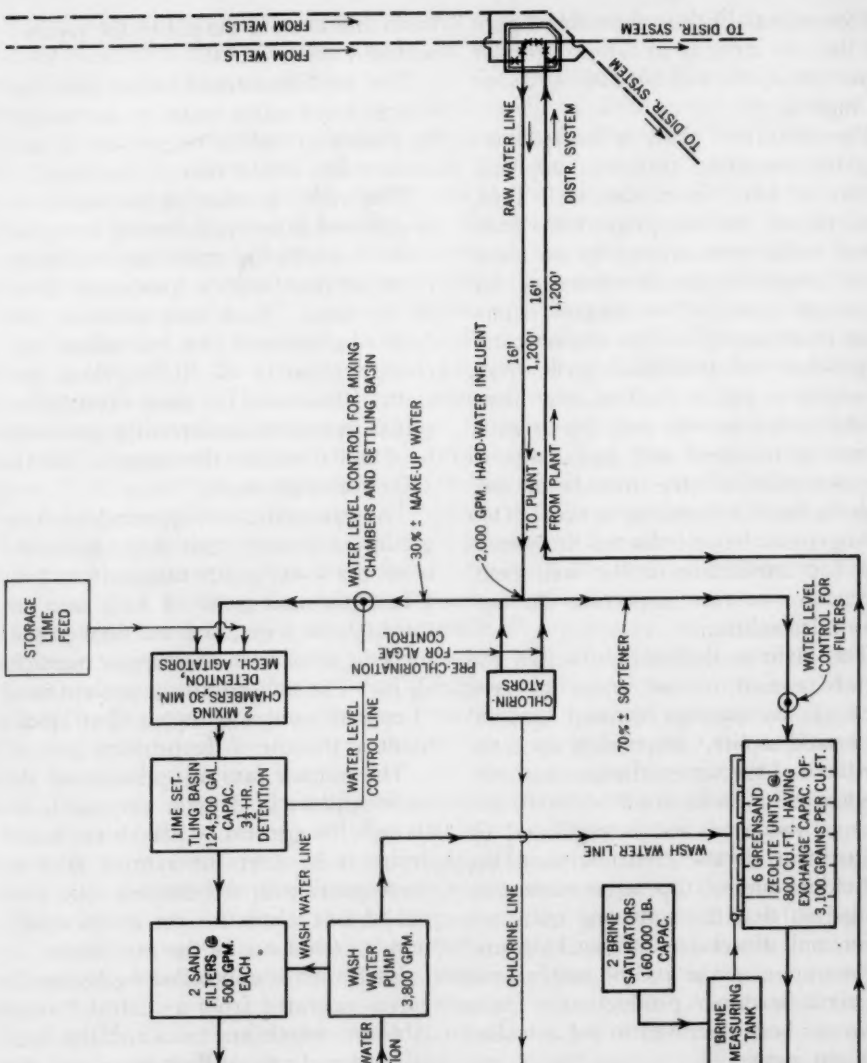
FROM WELLS
FROM WELLS
TO DISTR. SYSTEM
TO DISTR. SYSTEM
RAW WATER LINE
DISTR. SYSTEM
16"
1,200'
16"
1,200'
TO PLANT
FROM PLANT
WATER LEVEL CONTROL FOR MIXING CHAMBERS AND SETTLING BASIN
30% ± MAKE-UP WATER
2,000 GPM. HARD-WATER INFLUENT
STORAGE LIME FEED
2 MIXING CHAMBERS, 30 MIN. DETENTION, MECH. AGITATORS
PRE-CHLORINATION FOR ALGAE CONTROL
CHLORINATORS
70% ± SOFTENER
WATER LEVEL CONTROL FOR FILTERS
WATER LEVEL CONTROL LINE
LIME SETTLING BASIN 124,500 GAL. CAPAC. 3¼ HR. DETENTION
WASH WATER LINE
WASH WATER LINE
6 GREENSAND ZEOLITE UNITS @ 800 CU.FT., HAVING EXCHANGE CAPAC. OF 3,100 GRAINS PER CU.FT.
2 SAND FILTERS @ 500 GPM. EACH
WASH WATER PUMP 3,800 GPM.
CHLORINE LINE
2 BRINE SATURATORS 160,000 LB. CAPAC.
BRINE MEASURING TANK
WASH WATER SUCTION
FILTERED HARD WATER WELL 30,000 GAL. 200 TO 300 PPM.
MIXED FINAL WATER 75 PPM. 150,000 GAL. CAPAC.
SOFTENED WATER WELL—ZERO HARDNESS 150,000 GAL.
VENTURI METER
HIGH-LIFT PUMPING STATION

FIG. 1. Flow Diagram of Woodlawn Softening Plant (not to scale)

The softened water is stored in a 150,000-gal. clear well under the six zeolite filters. The outlet from the well is connected directly to a baffled chamber, at which point it is mixed with the output from the hard-water filters.

The balance of the raw water passes through two mixing chambers, each approximately 10 ft. 10 in. by 11 ft. 7 in. in plan and 18 ft. deep. Each basin is equipped with a mechanical agitator of the paddle type. At the designed capacity of the plant and at maximum hardness, the detention period in the mixing chambers is 30 min.

From the mixing chambers, the water passes to a weir box and is distributed into the lime settling basin, 24 ft. 6 in. by 43 ft. in plan and 18 ft. deep, with a capacity of 124,500 gal., sufficient to provide a detention period of 3½ hr. at designed plant output for hard-water conditions.

In this basin, the iron and manganese, generally present in amounts up to 1.0 ppm., are removed and the water softened by approximately 25 ppm. The lime-settled water is applied to two sand filters of the same dimensions and general construction as the zeolite units. The quality of the settled water is such as to permit filter runs of approximately 48 hr.

The filtered hard water is stored in a basin directly below the two sand filters. The well is arranged with a weir wall at sufficient elevation to maintain an adequate amount of hard water in storage to permit the washing of a sand filter or a zeolite unit for 5 min. at a rate of 15 gpm. per sq.ft. if desired. If it is found expedient to use soft water or water of intermediate hardness, this can also be accomplished by raising or lowering the elevation of the water in the various storage wells.

The soft and hard waters are mixed in a baffled chamber which leads to a finished-water storage well located under the pumping station proper. This well has a capacity of 150,000 gal.

All piping for sand and zeolite filters is located in the central pipe gallery at the same level as the pumping station operating floor. The level of water in the sand filters and in the zeolite units is controlled by a hydraulic valve actuated by the level of the water on the filters. In this manner, regardless of the head on the well pumps, there is no danger of overflow. The elevation of the water in the clear well is also regulated by means of a master controller which shuts off all filter units when the clear well becomes full.

Pumping Station Design

The pumping station for the plant is located at pipe gallery level. Three units of high-lift centrifugal pumps—one of 500 and two of 1000 gpm. each—discharge against a head of 200 psi. through a 16-in. cast-iron main. Space has been provided for a fourth unit when required. Normally, at the present time, the station is operated at a rate of 1500 to 2000 gpm.

Wash-water pumps for both the sand filters and the zeolite units are also located in this room. They take the suction from the hard-water well and discharge through a 12-in. pipeline to the wash-water system of each of the filters. If the operator desires to use hard water only for backwashing, this may be accomplished by maintaining the elevation of the mixed water well at a level below the baffle wall in the hard-water storage well. By raising the level in the mixed-water well, water of any desired hardness may be used for backwashing operations.

FIG. 1. Flow Diagram of Woodlawn Softening Plant (not to scale)

Each wash-water pump has a capacity of 3800 gpm. against a total head of 50 ft. The head on the discharge side of the pump may be maintained at any desired level by the setting of an automatic water relief valve to return excess water to the hard-water well. In general, the wash water required for the zeolite units is furnished at the rate of 11 gpm. per sq.ft., while, for the silica sand filters, the rate is raised to 15 gpm. per sq.ft.

All high-lift and wash-water pumps are maintained in operating condition by means of an automatic continuous priming system consisting of electrode chambers and vacuum tanks to start and stop a vacuum pump at a predetermined vacuum and to cut in a water ejector for priming in the event of power failure to the vacuum pump. The equipment is arranged so that it is impossible to start a pumping unit not properly primed and to shut down any unit upon loss of prime.

The pumping station also houses the brine-measuring tank and the brine pump. The brine is drawn from outside saturator tanks, diluted to approximately 20 per cent and pumped to the units.

The controls for pumping equipment are located in a central control room on the filter operating floor. The wash-water and brine pumps may be started either at the control board or at a central station in the filter operating room, where the brining and washing operations are visible to the operator. The brine pump is normally shut down by float switch control in order to insure exact dosage of the individual zeolite units.

On the control panel are also mounted the audible telephone control circuit for the remote starting and stopping of the seven raw-water well pumps, the recording Venturi meter for the measurement of the output of finished water, the recording pressure gages for the pumps and water level recording gages for the hard-water and the mixed-water storage wells. On the same board is also mounted the gage to indicate the level of the water in the distribution reservoir, approximately 2½ miles distant.

In general, the power requirements for the station are furnished at 440 volts from a substation located immediately adjacent to the building.

The operating floor over the pumping station houses an office, an adequate laboratory equipped for all routine chemical determinations for the control of the plant and a sampling table which permits the chemist to draw samples from any of the operating units of the station. In the main filter building are also provided a separate chlorinator room and the conventional utility room, toilet, showers and storage facilities.

Design of Building

The filter building proper is a single-story structure of brick and terra cotta trim. The main lobby and filter room are constructed of ceramic tile to reduce to the minimum the cost of maintaining a clean and attractive appearance. All floors in the main portion of the building are of terrazzo.

The chemical feed and storage building is a two-story brick structure, constructed over the mixing chambers and settling basin. The space over the mixing chamber houses the dry feed machines and the agitator drives. Each dry feeder is equipped with a hopper to permit loading from the storage floor above.

The floor over the settling basin affords ample space for a meter testing

and repair shop and a machine shop for ordinary repairs of all station equipment. The second floor of the chemical building is devoted entirely to the storage of lime and the loading of the hoppers of the dry feed machines. Ample space is available for two cars of lime. A railroad siding extends to the rear of the building and permits the direct loading and transfer of chemicals to final storage by means of an electric hoist and a trolley system.

Salt is purchased in bulk in carload lots of 60,000 lb. and is stored in one of two saturators, each having a capacity of 80,000 lb. Each saturator is equipped with a gravel filter underdrain and a perforated pressure piping system to insure complete saturation of the brine. The water level in the saturator bins is maintained at constant level by means of float valves.

The entire plant is heated by means of gas, and heat is distributed to the larger units of the plant through ventilating type unit heaters and to the remainder of the plant by means of convector radiators. The ventilation provides for six complete changes of air per hour and is sufficient to insure the absence of excessive moisture in the pump room, filter gallery and filter operating room.

Operating Results

As previously mentioned, the water supplied to consumers for many years had a hardness varying from 250 to 350 ppm., with iron and manganese present generally in amounts above desirable limits. Complaints of "red" and "black" water were rather numerous. In the year immediately prior to the completion of the softening plant, the water served to consumers approximated the hardness of previous years, but, in general, iron and manganese were not present in objectionable amounts.

The plant was put in operation in March 1942. For a period of two weeks, the water served to the consumers was softened from 300 to 200 ppm. For the next two weeks, the hardness was reduced to 150 ppm., followed by a two-week period at 125 ppm. Thereafter, the water was softened to the final lower limits of 75 ppm. This procedure was adopted to minimize any effect of the change in the quality of the water on deposits either in the mains or in the house plumbing lines. In all of these operations, the pH of the finished water was maintained between 7.8 and 8.0. Very few complaints were received and in all cases these were from isolated locations. The transition from hard to soft water was scarcely noted by the consumers, except that stores and laundries did comment upon the sudden drop in the sale and use of soap. Very few persons mentioned any change in taste of the water.

In general, the plant has been operated to obtain an exchange capacity of zeolite varying from 3300 to 3500 grains per cu.ft. with a salt consumption of 0.35 lb. per thousand grains of hardness removed. The average run of the zeolite filters is approximately 5 hr. In routine practice, three or four zeolite units have been run in conjunction with one silica sand unit to produce the desired quantity of water with a hardness of 75 ppm.

For the first few months there was a tendency to use excessive amounts of water for plant purposes, particularly for backwashing and rinsing operations, with the result that during the first three months, the total amount of water consumed at the plant approximated 15 per cent of the incoming

water. Later, the schedule adopted showed that entirely satisfactory results were obtained by washing the zeolite units for 3 min. at the end of each run and rinsing for 30 min. at a rate of approximately 300 gpm. The sand filters have been washed for approximately 5 min. at a rate of 15 gpm. per sq.ft. After adoption of this schedule, the total use of plant water has varied from 9 to 10 per cent of the incoming water.

One of the noteworthy facts concerning the operation has been the close control of a hardness and pH of finished water without the use of mechanical mixing devices. In routine operation, this control has been accomplished by apportioning the amount of water to be passed through the zeolite units and the make-up water and depending upon the relative levels of the wells and the baffled chamber for thorough mixing of the water. In general, it has been possible to control the finished water at all times within a hardness range of 73–77 ppm. In like manner, the pH has also been controlled between 7.8 and 8.0.

The cost of producing the soft water including high-lift pumping from the wells against a head of 200 psi. and including chemicals and labor, has varied between 10 and 11 cents, depending upon the plant output. The total investment in the new plant, including the acquisition of land, the construction of the railroad siding and the substation, the softening plant and the seven wells and control equipment, is approximately $400,000.

Effect on Rates

Prior to the construction of the softening plant and the new ground-water supply, the rates for service were low. The minimum charge to consumers under the old schedule was $2 per quarter, which entitled the consumer to use 7500 gal. of water. Corresponding rates for larger consumption varied from $0.25 to $0.14 per thousand gallons. The rates for service were revised upward upon the initiation of softening, so that the minimum charge is now $3 per quarter for 6000 gal. Rates for larger consumption vary from $0.40 to a minmum of $0.20 per thousand gallons.

The rates to the average consumer were increased approximately 50 per cent. Despite such a substantial increase, however, the consumers have been generally satisfied to pay for the advantage of soft water.

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

WATER QUALITY

Comparison of the New Canadian and U.S. Water Quality Standards. NORMAN J. HOWARD. Can. Engr.—Wtr. & Sew. **81:** 2: 9 (Feb. '43). U.S.P.H.S. and Canadian water qual. stds. discussed. Suggested that, inasmuch as conditions in Dominion closely parallel those in U.S., former should be adopted in Canada. Examn. of 100-ml. portions for coliform bacteria routine practice in Toronto for many years. In '42, 5951 samples from distr. system examd., only 2.01% of which contained coliform bacteria, notwithstanding fact that raw water heavily pold. with sewage. Collection of chlorinated water samples in Na thiosulfate-treated bottles routine practice for some time.—*R. E. Thompson.*

Sanitation Manual for Land and Air Conveyances Operating in Interstate Traffic. ANON. Pub. Health Rpts. **58:** 159 (Jan. 29, '43). SEC. I. *Sources of Water Furnished to Interstate Carrier Conveyances:* Water for drinking and culinary use on interstate land and air conveyances shall be of qual. prescribed by U.S.P.H.S. Drinking Water Stds. and secured only from supplies approved in U.S. Interstate Quarantine Regulations, '21. Items in following sections further elaborated under headings pub. health reason and satisfactory compliance. SEC. II. *Delivery of Water to Conveyance:* Considered from standpoints of hydrants, water hose, water buckets and ice handling. SEC. III. *San. Facilities at Terminals and Yards:* Places for servicing land and air conveyances, such as depots, coach yards, bus stations and airfields shall be provided with all san. facilities essential to protecting pub. health. Equip. and facilities of adequate nature and extent shall be provided so that water, ice, foods and cleaning of conveyances handled or accomplished under acceptable conditions. Wastes disposal, impure water supplies, platforms at servicing areas, excreta disposal at terminals and yards, water cooler and filter cleaning equip., handling food and drink supplies, cleaning conveyances, san. facilities for and cleanliness of employees and freedom of latter from communicable disease discussed. SEC. IV. *San. Condition of Conveyances:* Shall be such as not to facilitate interstate spread of any communicable diseases enumerated in U.S.I.Q. Regs. and to this end conveyances shall be maintd. and operated in satisfactory manner for health protection. Conveyance toilet and lavatory facilities, discharge of wastes from conveyances at stations, from conveyances en route, their cleanliness, ventilation and heating discussed. SEC. V. *Water Supply Facilities of Conveyances:* Equip. on conveyances for water storage and distr. for drinking and culinary purposes shall be satisfactory. Conveyance water system, water filling connections of railway conveyances, conveyance water coolers, water filters, drinking water dispensing and use of const. temp. bottles for water discussed. SEC. VI. *Conveyance Dining Space Facilities:* Equip., facilities and conditions on land and air conveyances relating to storage, prepg., handling and serving food and drink shall be such as to assure health protection of consumers. Subject further detailed under general specifications, compliance with interstate quarantine regulations and misuse of dining

space facilities. SEC. VII. *San. Qual. of Food and Drink:* Foods and beverages provided on land and air conveyances shall be of such qual. and stored or served under such conditions as not to become agents for interstate spread of any communicable disease. Wholesomeness, storage and refrigeration of food and drink discussed.—*Ralph E. Noble.*

Inspection Program Adopted for Semi-Public Water Supplies. EVERETT C. HANDORF. W.W. Eng. **95:** 193 (Feb. 25, '42). Memphis, Tenn., established routine inspection control over many water supplies on private premises. Function of the city health dept., activity supported by city and water com. ordinances and codes (published). Code explains need of ordinance, hazards of cross-connections, adequate protection, review of water-borne typhoid outbreaks, dysentery and diarrhea traced to water supplies in U.S. since '20. History of Memphis water supply development briefed. City and county health depts. co-operate. Underground flow between wells traced by acid treatment and pH detns. Inspections of each supply made twice each year, samples taken monthly, and questionable supplies followed up as indicated and required by san. surveys or lab. reports. Routine inspection sheets used. Wells classified as public, quasi-public, cross-connected to city supply, dual supply, strictly industrial and strictly private. Cross-connections protected. Annual fees charged and permits issued for use, permits for repair and permits for new constr. (based on approval of filed plans). Stds. of constr. enforced. Provision of sampling cocks required. Required water treatment and storage described. Std. pipe color scheme enforced to facilitate identification. Filling of abandoned or obsolete wells inspected. Possibilities of poln. stressed and chem. anal. also used to aid in its detection. Private and public wells subject to fire dept. use, and in other emergencies. Inspection program control, enforcement and service program with stress given to education and fact-finding surveys.—*P.H.E.A.*

Laboratory Policies and Requirements in the Examination of Water. O. COSTA MANDRY. Puerto Rico Health Bul. **5:** 411 (Dec. '41). Comprehensive review of public health importance of water supplies. Methods of disease transmission by water supplies and several types of water occurring in nature described. Procedures in certification of drinking waters and stds. of U.S. Public Health Service outlined. San. surveys, methods of sampling and signif. of chem. and bact. anal. described. Data on existing water supplies of Puerto Rico and their adherence to U.S.P.H.S. Stds. Figures show that in '41, total of 75% of urban pop., representing 25% of island's total, served with water receiving some kind of purif. Remaining pop., located largely in rural areas, still uses raw water potentially subject to contamn. No supply meets all requirements for certification under U.S. Stds. —*P.H.E.A.*

TREATMENT—GENERAL

Treatment of Water for Domestic and Industrial Requirements. ALBERT PARKER. Engineering (Br.) **154:** 37, 44, 77 (July 10, 17, 24, '42); J. Inst. Civ. Engrs. (Br.) *No.* 8: 365 (Oct. '42). Although water available from rain in Great Britain about 20 times as great as quant. required for domestic and industrial purposes, water-supply undertakings and industries frequently experience difficulties in obtaining suitable supplies within reasonable distance. Water Poln. Research Bd. stressed importance of accurate information on water resources and on variations with different conditions of weather. After ensuring that source for public supply or for certain industrial purposes kept as free from poln. as possible, next step to decide on treatment necessary to render water suitable for purpose required. Removal of coarsest suspended matter can be achieved by simple sedimentation in reservoirs or tanks. Removal of fine suspended and colloidal matter effected by addn. of chem. coagulant, followed by mixing, sometimes sedimentation and filtration of water through fine sand. Storage of water exposed to light may give rise to growths of algae. In overcoming difficulties caused by algae, prevention better than cure. Prevent contamn. of water by nutrient substances; add $CuSO_4$, 0.1 to 1.0 ppm., potassium permanganate, 0.2 to 0.5 ppm., or Cl_2, 0.5 to 1.0 ppm. Difficulties sometimes caused by excessive growths of true water weeds and of emergent weeds. Effort should be made to maintain bed as clean as possible to prevent access of mud and polg. org. matter with inflowing streams. Growth of water weeds can be prevented or discouraged by adding sodium arsenate to

about 2 parts arsenious oxide, or 1.5 parts arsenic, in 1,000,000 parts of water. This concn., when applied only occasionally, not poisonous to animals. Emergent weeds can be killed or discouraged by spraying them 2 or 3 times at intervals of few days with a 2.5% soln. of sodium chlorate. In this concn. not poisonous to animals bat clothes satd. and allowed to dry highly inflummable. Growths which cause difficulty in condensers and coolers can be prevented by adding 5 to 10 ppm. free Cl_2, repeated at intervals of few days. $CuSO_4$ should not be added in condenser tubes as it may have a destructive action. Both slow and rapid filters have advantages and disadvantages. Advantages of using rapid filters as prelim. to passage of water through slow filters. Cl_2 added for sterilization generally between 0.1 and 0.5 ppm. Excess of free Cl_2 gives rise to chlorinous taste. Application of Cl_2 so widespread that tendency to relax efforts to reduce poln. of water supply at source. Tendency to be deprecated. Other methods of disinfection include addn. of excess lime of about 10 ppm., treatment with ozonized air, ultra-violet light, and oligodynamic action of certain metals. Larger quants. than 0.1 to 0.5 ppm. of iron or manganese may render water unsuitable for certain industrial purposes. Methods of removal include aeration, addn. of lime, sedimentation and filtration. At some works, water softened to reduce hardness to approx. 100 ppm. Water softened by treatment with lime or base-exchange processes. Three types of base-exchange zeolites in common use: natural glauconites, treated clays and synthetic products prepared from sodium aluminate and sodium silicate. Exchange value of some resins a little greater than that of synthetic alumino-silicates, and have advantage that they are not destroyed by dil. solns. of acids or alkalis. Can be regenerated with sodium chloride to give sodium compd which can be used in same way as alumino. silicates, or can be regenerated with acid to give hydrogen compd. Considerable quants. of base-exchange materials made from coal now in use on commercial scale. Some natural waters, especially soft waters of moorland origin, have marked corrosive action on iron mains, galvanized steel tanks and lead service pipes. Methods of treatment employed include addn. of lime, chalk, soda and sodium silicate; passage of water through beds of limestone, marble and magnesite; and removal of dissolved CO_2 by aeration of water. Question of whether iodine deficiency in water is cause of endemic goiter long subject of controversy. In some districts, supplies contain abnormal quants. of fluorine—4 or 5 ppm.—which give rise to mottled enamel of teeth. Treatment with calcium phosphate one of most successful methods. *Discussion.* [J. Inst. Civ. Engrs.] W. J. E. BINNIE: Avg. annual runoff from catchment area can be estd. from rainfall and extent of area after making deduction for loss by evapn., etc. Min. flow of river independent of avg. annual rainfall as water enters stream from ground storage. Removal of gases from water found to reduce corrosive activity to $\frac{1}{16}$. H. T. CALVERT: Not much point to carrying out inland water survey merely to pigeon-hole data. Success of Royal Com. on Sewage Disposal due largely to fact that it not confined to taking evidence. H. F. CRONIN: Combination of rapid filters and slow sand beds enable more water to be filtered at lower capital cost and smaller running cost than slow sand units only. Failures or bad samples obtained from slow sand units can nearly always be traced to ground-water infiltration. E. B. BAILEY: Fair to say that *any* inquiry regarding underground water half answered at time asked because so much hydrogeol. information collected. Little fluorine helpful, but little doubt that more than certain quant. seemed to introduce difficulty. PHILIP PORTEOUS: Whereas more than 5000 rain gages established in British Isles, percolation measured at only six stations. With synthetic zeolite, weight of salt required in regenerating varied in proportion to bulk of zeolite provided; in Cambridge plant, paid handsomely to use excess of zeolite to reduce salt consumption. W. G. MOFFITT: Corrosion often occurs when large institutions use softened water in hot-water system. More satisfactory if water can be softened at water works rather than at separate points. In that way corrosion difficulty would be remedied. JULIUS KENNARD: Rapid progress made in sterilizing supplies since epidemic at Croydon. At reservoir in West England about 11 yr. ago, activated carbon distributed on surface at rate of 5 ppm. Within 48 hr., carbon had settled to bottom and brackish taste and odor (due to *Chara*) had disappeared. A. C. GARDINER: Some years ago, small reservoir treated with 2.2 ppm. copper sulfate to combat *Fragillaria*. Effect immediate and water became clear, but within few days small green algae appeared and water became grass green. Condition

persisted although concn. of copper sulfate did not fall below 1.6 ppm. May be practicable to kill algae with copper sulfate, but first species may be succeeded by second more resistant. H. C. WHITEHEAD: Growing similarity between work of water engrs. and others engaged in sewage purif. Re-use of water for domestic and industrial requirements more general than imagined in all parts of world. *Author's Closure:* Only principles of methods for dealing with problem of algae and weeds can be stated, as each body of water has its own special characteristics. Doubtful if coagulants will reduce quantity of $CaCO_3$ deposited in filter although it might be deposited in form more easily removed on backwashing. *Discussion by Correspondence:* S. B. JACKSON: On basis of cost anal. of water conditioning in modern high-pressure, high-temp. steam plants, adoption of co-ordinated boiler-feed conditioning, including chem. proportioning would result in capital saving of 5.0 to 7.5% in comparison with lime-soda and evaporator scheme. W. N. MCLEAN: In Great Britain, ropeway and suspended meter will usually suffice for recording water velocs. above 3 or 4 ips. Maint. of continuous records absolute necessity. T. H. TURNER: Success of locomotive feed-water treatment largely due to addn. of sodium aluminate, which almost completely softens bad waters contg. magnesium. Sufficient evidence not yet available to show whether Langelier index of real value. R. C. S. WALTERS: Some waters softened by base exchange result in weak supply of Epsom and Glauber salts. Difficulty of sludge disposal in lime-soda process should not be overemphasized, for sludge may have market value. J. NOEL WOOD: Author's avg. of 20–25 gpd. (Imp.) per capita consumption may be accurate for England, but does it include enormous quants. supplied for Scotland? *Author's Reply:* In many parts of Scotland domestic water consumption much greater than 20–25 gpd. (Imp.) per capita, but, allowing for smaller population in Scotland, figure is fair avg.—*H. E. Babbitt.*

Developments in the Treatment of Water. ESKEL NORDELL. Paper Tr. J. **115:** 15: 23 ('42). Description and discussion of various modern types of water-softening treatments. Spaulding pptr. can be used for: (1) softening water to any required deg. down to ultimate limit of about 17 ppm.; (2) removal of SiO_2 from water by use of dolomitic lime; (3) removal of turbidity and color; and (4) removal of tastes and odors. New rectangular designs require less space and are simpler to construct than conical or pyramidal designs. "Spiractor" new type of cold lime-soda softener which requires only a 5–10 min. detention period and produces granular byproduct instead of usual sludge. Rotary surface washer device which elims. mud-ball formation from filters and requires only 0.5–1.0 gpm. per sq.ft. of filter area for its operation. Carbonaceous or org. zeolites can be employed either on Na cycle, regenerated with NaCl, or on H cycle regenerated with H_2SO_4. When employed on H cycle, will remove Na as well as Ca and Mg. Water demineralized by passing it first through H zeolite, then through degasifier. Results given show that effluent compares very favorably with distd. water while the avg. operating cost only some 5–15% of cost of distn.—*C.A.*

Some Considerations in the Purification of Water. NORMAN J. HOWARD. Eng. Cont. Rec. **55:** 15: 36 (Apr. 15, '42). Sources of supply should be investigated carefully and purest one selected, providing cost not unreasonable. Possibility of taste and odor should not be overlooked. Installation of exptl. plant to det. most suitable coagulant and optimum conditions for floc formation and settlement advisable. Modern rapid sand plants usually designed to operate at rate of 2 gpm. per sq.ft. Sand size should be not less than 0.5 mm. Although slow sand filtration not frequently employed in America owing to climatic conditions or phys. quality of raw water to be treated, process usually gives higher bacterial eff. than rapid sand filtration and is more effective in dealing with water subject to taste and odor. Treatment for reduction of hardness and correction of corrosiveness may be required. Other objectionable mineral constituents include Fe, chlorides, if in sufficient concn. to cause taste, and Pb. Permissible limit for Cu will probably be raised from 0.2 to 0.5 ppm. Most serious present-day problem is poln. due to indus. wastes and lack of adequate sewage treatment.—*R. E. Thompson.*

Ozone in Water Treatment. STANLEY JENKS. Am. City. **57:** 6: 64 (June '42). Recent developments in equip. and reduced elec. power costs have made ozonation of water dependable and economical process in water treatment. 10 yr. ago 25 kwhr. per lb. ozone produced required; today only 16 kwhr. used.

Made possible by improved air-conditioning and drying equip. and chems. More efficient heat dissipation considerably lengthened life of dielectric. Ozone treatment valuable because of powerful oxidizing action; excess dosage produces no harmful effects; relative simplicity of application and ability of testing residuals with ortho-tolidine.—*F. J. Maier.*

Sanitation and Purification of New York City's Water Supplies. FRANK E. HALE. J.N.E.W.W.A. **55:** 52 (Mar. '41). Methods for safeguarding N.Y.C. water supply given. Use of water about 980 mgd. from watersheds of 1136 sq.mi. and several well fields in Queens and Brooklyn. Storage first line of defense and avg. of 60 days' storage available. Microorganism and bact. detns. made at varying depths in reservoirs and at established sampling points. Aeration used on Catskill water as it leaves Ashokan. Cities on watersheds have their sewage treated usually by sludge digestion, sand filtration and chlorination of filter effluent. All surface water chlorinated at least twice and all wells that require it chlorinated. All cases of typhoid fever on watersheds carefully checked over by city. Turbidity controlled by use of alum added to aqueduct between 2 reservoirs. From 1.6 to 0.35 gpg. added with enough lime hydrate to neutralize acidifying effect of alum. Several iron-removal plants operated on well water supplies. Micro-organisms occur throughout reservoirs, and these controlled by copper sulfate, increased chlorination and change of point of draft. 3 labs. make phys., chem., bact. and microscopical examns. of water supply and sewage plant effluents. Also check pipelines added to distr. or supply system. Charts and tables included showing work of lab. div. and results obtained.—*P.H.E.A.*

How Woodstock, Ill., Met Its Hard-Water Problem. LESTER E. SWAIN. Am. City **57:** 8: 55 (Aug. '42). Water supply for Woodstock, Ill., obtained from 2 deep wells has hardness of 380 ppm. Water softened in cold-lime treatment plant of 1 mgd. capac. With demand reaching 2 mgd., new plant of 3 mgd. capac., consisting of 2 Spaulding precipitators completed. Increased capac. required no increase in ground space, since precipitators installed in 2 former settling basins. Hardness reduced to 85 ppm., lime deposits in mains elimd., filter washings cut in half and pH control better.—*F. J. Maier.*

CHEMICAL FEEDING, CONDITIONING, SEDIMENTATION

Consumption of Chemicals by Municipal Water Works in Canada. ANON. Can. Engr.—Wtr. & Sew. **80:** 10: 23 (Oct. '42). Dominion Bur. of Statistics data for '40 and '41. '41 consumption in tons, by 217 water works using chems: alum, 4764; chlorine, 751; lime, 2568; salt, 500; soda-ash, 524; sulfur dioxide, 105; chloride of lime, 33; activated carbon, 33; ammonium sulfate, 66; anhydr. ammonia, 4. Consumption of specific chems. by provinces and municipalities tabulated.—*R. E. Thompson.*

Experiments for Increasing the Rate of Flow of Chlorine Gas From Standard Cylinders. N. N. KUZNETSOV. Vodos. Sanit. Tekh. (U.S.S.R.) *No. 10:* 54 ('39); Khim. Referat. Zhur. (U.S.S.R.) *No. 3:* 81 ('40). Elec. thermostat constructed to compensate for loss of heat from evapn. of Cl_2. Thermostat equipped with contact manometer which disconnects heaters on increase of pressure in collector. Use of elec. thermostats under production conditions decreased required no. of Cl_2 cylinders from 260 to 30, with corresponding decrease in connecting lines and no. of parts.—*C.A.*

Handling Shipments of Liquid Chlorine. ROBERT J. QUINN. Chem. Indus. **51:** 872 (Dec. '42). *Equip. for Handling Dry Chlorine:* As liq. or gas, ordinarily iron, brass or copper used for equip. for handling Cl_2 as liq. or gas. Piping for liq. should be at least of $\frac{3}{4}$" extra-heavy black iron; valves of heavy iron constr. with stems, seats and seat rings of resistant alloys. Graphitized packing recommended by mfr. provides sufficient lubrication. Other lubricants avoided because of chem. reaction. In long pipelines for liq. Cl_2, shut-off valves provided every 100'. Liq. Cl_2 expands 0.16% of its vol. with every deg. F. increase in pressure. As closed-off pipe, therefore, liable to rupture from hydrostatic pressure, should provide each section with expansion chamber of least 20% pipe capac., vertically above pipe. *Equip. for Handling Moist Chlorine:* In handling Cl_2 in contact with moisture, as in feeding into soln., silver, chem. lead and special alloys suitable. *Shipping:* Liq. Cl_2 shipped in

following net wt. containers: single unit tank cars holding 16 and 30 tons; multi-unit cars carrying 15 1-ton containers; and cylinders holding 100, 105 and 150 lb. Outside temp. in relation to expansion property of Cl_2; discharge from containers; safety devices; protective measures; limiting pressures; air padding; storage temps.; feeding Cl_2 into liq.; valve leaks; and first-aid measures detailed.—*Ralph E. Noble.*

Making a Phosphate Control System Work. J. W. ADLUM. Power Plant Eng. **46:** 12: 70 ('42). Phosphate treatment supplementary to lime and soda ash softener. At outset, control of phosphate feed erratic and unsatisfactory. Special spark-plug control to indicate depletion of phosphate in pressure tank installed. Removal of iron hydroxide floc, which resulted in clogging control valve, accomplished by special mixing tank. Operation and results described. Several illustrations make description clear.—*C.A.*

Round-up of the Water Conditioning Situation Under War Conditions. REGINALD TRAUTSCHOLD. Rayon **23:** 427 (July '42). *"Red Water" Troubles Controlled—Threshold Treatment Found Effective:* Iron and steel pipe corrosion, traceable chiefly to passing water of low pH, giving hydrated iron oxide carried as "red water" or pptd. over regions of corrosion. "Red water" commonly treated with lime, caustic soda or soda ash with questionable results. Frequently, treatment fails to stop corrosion, simply decreasing difficulties by pptg. iron oxide and increasing tuberculation. More effective and economical procedure, threshold treatment using vitreous sodium phosphate to form protective film adsorbed on pipe surface, definitely inhibiting corrosion. Pennsylvania woolen mill used Schuylkill R. water. At test, pH varied from 6.6 to 8.1, with hardness 68 to 148 ppm. Eff. zeolite softener reduced latter to 10 ppm. as $CaCO_3$ but, as usual, increased iron content thereof. Daily water samples from softened water and dye house, mixed into carefully measured weekly composite samples. Such mixtures then anald. to det. iron pick-up in distr. system. Threshold treatment started Jan. 3, '40, feeding 8 ppm. of vitreous sod. phos. into soft water tank dischg. Reduced to 6 ppm., Jan. 26; to 4, Feb. 14; to 2, May 1. Iron pick-up reduced to negligible amt.; decidedly worth while. *93% Effective:* At one large bleachery, 2-wk. treatment reduced iron content of water supply from 1.75 to 0.56 ppm.; after 2 mo., to 0.12 ppm. Cash dividend therefrom substantial. *Microbiological Control—Chlorination Protects Mill Processing:* Chlorination for microbiol. control received much attention in recent yr. to protect mill processing equip. and fabrics produced, against bacteria, molds and algae in supplies. In extreme cases, slime development in plant water lines gave difficulty when accumulations broke away and lodged within fabrics. Gelatinous capsule-forming organisms attacked cellulose and rapidly built up capsular material from decompn. products, growing rapidly under favorable conditions. Carbonic and lactic acid formation lowered pH of soln. These slime troubles closely parallel more serious slime troubles in pulp and paper mills where control effected by chlorine alone, or with ammonia to form chloramine. Where use of latter practical, ammonia-chlorine treatment more economical of Cl_2.—*Ralph E. Noble.*

Deacidification of Water. ERIC L. HOLMES, LUCIF E. HOLMES & WM. G. PRESCOTT (to the Permutit Co.). U.S. Pat. 2,281,194 (Apr. 28, '42). Water such as that contg. very small proportion of HCl and H_2SO_4 deacidified by contact with extensive surfaces of resin-impregnated carrier made by treating inert material such as ground coke or pumice stone first with org. amine such as *m*-phenylenediamine-hydrochloride and then at elevated temp. with aldehyde such as paraformaldehyde capable of forming at such temp. an insol. acid-absorbing condensation product with amine. Treating material regenerated from time to time by washing with dil. alk. solns. Various details given.—*C.A.*

Deacidification of Water by the Magno Process. A. F. MEYER. Z. Ver. Dtsch. Ing. (Ger.) **85:** 866 ('41). Discusses experiences in use of Magno process for deacidifying water during 5 yr. since introduction. Automatic regulation of calcium-carbonic acid equilibrium has made process suitable for use in small water works, but necessary to wash filter regularly to remove solids retained. Process used for treating water supplies for industries and for swimming pools. Removal of iron and manganese of great importance. When iron present in inorg. form only, removed by Magno process alone; but when permanganate demand of water more than 12 mg./l., prelim. coagulation necessary. If

content of manganese less than about ⅓ of that of iron, removed with iron, but frequently time must be allowed for formation of layer of compds. of manganese on filter medium, which then adsorbs further manganese. Water produced by Magno process clear and free from iron and manganese and has stable calcium-carbonic acid equilibrium; this, however, does not prevent formation of protective layer over metal. Synthetic material (Magno-Syn) now produced, in which structure and chem. compn. can be adjusted more easily than when material obtained from dolomite (Magno-Dol).—*W.P.R.*

Sedimentation Basins for Water Purification. HUGO ALBERTELLI. Bol. Obras Sanit. Nación. **6:** 204, 292 (Sept., Oct. '42). *Part I:* Review of theoretical principles involved and std. practice in sedimentation basin design followed by description of important installations of this type in Argentina. Since Spanish terminology on subject not well established at present, author suggests use of generic name *decantadores* to include all types of sedimentation basins. Term proposed for plain settling basins *aclaradores*, while that for basins in which sedimentation aided by coagulants *depositos de coagulación*. For most part, ref. made to std. U.S. practice in basin design although, in discussion of methods for intermittent sludge removal, mention made of multiple hopper bottom installation at Stuttgart (Germany) where hydrostatic pressure of water in basin used to flush out sediment by periodic operation of valves at bottom of hoppers. Emphasis placed on importance of location and design of sedimentation basin inlets and outlets, as well as on devices to minimize short-circuiting. Std. types of mech. equip. for continuous sludge removal discussed and illustrated. *Part II:* Tabulated summary of principal sedimentation basin installations in Argentina. Of 36 basins described, 29 in plants operated by Natl. San. Works Dept., 3 in installations controlled by a Provincial (State) Govt., 1 municipally owned and 3 managed by private companies. Presettling facilities to remove coarser particles during periods of unusual water turbidities available at 12 of plants surveyed. Raw water turbidities vary from 12 to 15 ppm. at some plants, while at others fluctuate between 5 and 4000 ppm. About ¾ of basins described of rectangular type varying in ratio of length to width from 4 : 1 to 2 : 1. Depths fluctuate from 1.50 to 4.50 m. Table includes 3 square and 6 circular units varying in depth from 2.30 to 3.20 m. Usual theoretical retention period varies from 2 to 6 hr., although at some installations as long as 10 to 18 hr. At most plants, draining and cleaning method of sludge removal used. Other data included in table for each installation are: name of locality, water source, max. and avg. daily water consumption in '41, vol. of water treated, number of sedimentation units, type of inlet and outlet devices, length of water travel in basin and system of sludge removal. In plants being remodeled and on new installations, trend towards installation of presettling basins where high turbidities expected, elimn. of around-the-end baffling, provision of hopper bottoms near basin inlets and more general use of weirs at inlets and outlets.—*J. M. Sanchis.*

Sedimentation Tank Design Claims 93.3% Efficiency. ANON. Eng. Cont. Rec. **55:** 30: 16 (July 29, '42). Brief description of sedimentation basin developed by Robert Walton and Thomas D. Key at Alexandria, Egypt, after 12 yr. experimentation. Basically, unit consists of tank of any desired shape with very wide inlet and outlet and special internal baffles with submerged apertures at top through which water passes from one section to another. Recognizing that much loss in eff. results from irregular flow, tank designed to ensure uniform flow and eliminate vertical currents due to atm. temp. variations. At Alexandria, ordinary clarifier gives avg. eff. of only 60%, whereas new 0.935-mil.gal. unit, circular in shape and 110′ in diam., has removed avg. of 93.3% of suspended matter from highly turbid Nile R. water over period of 4 yr. Rate of flow is 0.22 mgd., providing 4 hr. settlement.—*R. E. Thompson.*

Water Clarification and Supply System. HARVEY A. WATSON. U.S. Pat. 2,271,165 (Jan. 27, '42). Use made of well pump, aerator connected by pipe line to well pump into which pump discharges, sedimentation tank having opening in communication with aerator into which aerator discharges, second pump connected by pipe lines to sedimentation tank for drawing water from tank, pressure tank connected by pipe line from second pump into which pump delivers, water-purifying device, pipe line connecting the pressure tank and water-purifying device, valve in pipe line to cut off flow of water from pressure tank to purifying device, and valve-controlled outlet

in pipe line and communicating with pressure tank ahead of first-mentioned valve, whereby when first-mentioned valve opened water discharged direct from tank.—*C.A.*

Separation of Impurities From Water by Use of a Precipitating Agent. CHARLES H. SPAULDING. U.S. Pat. 2,272,026 (Feb. 3, '42). App. described and method of purifying supply of water contg. impurities to be pptd. which involves maintg. zone of upwardly increasing area (as in conical tank), mixing impurity-laden water with pptg. agent, introducing mixt. into lower portion of zone at velocity sufficient to support substantially all impurities and ppt. therein, passing mixt. upwardly through this zone wherein fine impurities and ppt. aggregate, simultaneously progressively diminishing velocity of mixt., velocity at intermediate portion of zone below top thereof being insufficient to support impurities and ppt., whereby velocity-supported blanket of impurities and ppt. created immediately below intermediate portion of zone and area contg. clear water moving at low velocity provided above intermediate portion, withdrawing water highly concd. with aggregated impurities and ppt. from area of blanket as divergent side stream, and withdrawing clear liquid from low-velocity area.—*C.A.*

Clarifying Liquids Such as Water Supplies, Sewage and Industrial Wastes. SAMUEL L. TOLMAN (to the Jeffrey Mfg. Co.). U.S. Pat. 2,266,097 (Dec. 16, '41). App. described and method of flocculation which involves subjecting liquid flowing through a flocculator to flocculating action in successive stages by subjecting liquid to successive circular motions from energy source independent of liquid flow and about horizontal axes and confining flow of liquid from one stage to next substantially along axis of rotation of liquid and closely adjacent to such axis.—*C.A.*

FILTRATION

The New Filtration Plant of Newport News, Va. REEVES NEWSOM. W.W. & Sew. **89:** 12: 501 (Dec. '42). Completed in Sept. '42, Newport News filtration plant first major water works project completed by Dept. of Pub. Wks. largely with Lanham Act funds. '39 water consumption raised above avg. 4.5 mgd. because of shipyard activities. Present max., 12 mgd., shared by older plant. Either plant, with corresponding pumping stations and force mains, could carry 75% of peak demand during emergency repairs to other. Plant consists of coke-tray aerator, low-lift pumps, chem. storage and feeding equip., 2 mech. flocculators, 2 settling basins for 4-hr. detention, four 1.5-mgd. "Wheeler" bottom filters with c-i. wash-water gutters (42″ per min. max. wash rate), 150,000-gal. concrete wash-water standpipe with pumps and high-lift pumps. All valves hydraulically operated from high-lift pump pressure. Auxiliary pump and pressure tank provides emergency power for valves. All pipe from 36″ to ¾″ diam. cement lined, including entrance sections of Venturi tubes. Electrically operated cone valves and 2–4″ combination relief valves and surge suppressors installed to reduce surge in high-lift discharge line. Contract included constr. of 3 operators' residences and laying of 17 mi. of 30″ to 12″ c-i. cement and bitumastic-lined pipe. Total cost $1,029,612. Material readily obtained in '41 under A-3 priority which had to be increased to AA-2X before completion of job.—*F. J. Maier.*

Micro-Straining—A New Development in Water Purification. P. L. BOUCHER. The Engr. (Br.) **173:** 42, 445 (May 22, 29, '42). With advent of automatic, continuously self-cleaning strainers became practicable to employ fine screens and machines fitted with wire cloth having up to 150 meshes per lin.in. Object of present investigation to develop straining process for water some 7 times finer, on a linear basis, than that provided by use of 100-mesh wire cloth. Coarse straining is use of apertures of any size down to $\frac{3}{16}$″; medium straining between $\frac{1}{8}$″ and $\frac{1}{64}$″; and fine straining down to 350 meshes per in. The 350-mesh wire cloth, which is probably finest mesh wire cloth mfd. in commercial quants., has aperture of 39 μ and in piece of cloth 2″ × 4″ nearly a million apertures. Even this material in many expts. made with different water samples, allowed much visible sediment to pass. Possibility of bright electro-plating this cloth studied with 3-fold object of reducing still further original 39 μ aperture, strengthening cloth and increasing resistance to corrosion. Samples prepd. having apertures of 25, 20, 10, and 5 μ. 20 μ aperture wire cloth,

for heads up to 1″, when passing water contg. not more than 20 ppm. of suspended solids, rating for 1″ difference of level is 174 vertical ft. per hr., compared with 19′ to 38′ per hr. for rapid sand filters. Flow through microfabric streamlined, and difference of head across a continuously self-cleaning strainer rarely more than 1″ or 2″. May be concluded from corrosion tests that 20 μ-aperture cloth can be used with confidence in waters having pH values between 5.5 and 9.0. Results of small-scale tests, with no large suspended matter in raw water, showed that greater part of all suspended matter removed by microstraining, except on days when water highly colored. Further series of tests using chem. treatment with object of flocculating suspended matter, including color, undertaken. Avg. reduction of floc and suspended matter nearly 80%, and color reduction excellent. Found that everything depended on phys. state of floc. Because of bulk of floc, deemed essential to have relatively high speed of drum rotation to avoid blocking of cloth. Results obtained from small-scale tests warrant initiation of full-scale expts. Micro-straining may be considered for: (1) peat-stained waters in conjunction with flocculation treatment; (2) silt-carrying waters with or without flocculation; (3) relatively pure natural waters for which, if straining necessary at all, finest possible deg. of straining obviously desirable. Examn. of debris removed by fine-mesh strainers shows that extraordinarily high no. of particles small enough to have passed through mesh removed from water. Action can be explained by effect of partial clogging which arrests smaller particles. Effect appears to be greater the finer the mesh. Very large proportion of plankton of such size and shape that they are readily removed from water by straining fabric with 20 μ apertures. Bacteria cannot be removed by straining unless floc present in water.—*H. E. Babbitt.*

Pressure Filtration Practice. ANON. Wtr. & Wtr. Eng. (Br.) **45:** 129 (Oct. '42). Works comprise one large and two small pressure filter plants. Supplies drawn from impounding reservoirs on peat-covered moorlands which form watershed. Waters supplied to stations B and C similar in summer, but differ in winter. Filtered water from stations A and B pass directly into distr. system. Station C delivers water into clear-water basin. All three stations receive acid waters with pH ranging from 3.1 to 6.0. At stations B and C weak soln. of aluminum sulfate in specific quants. pumped into inlet to filters. Coagulant at A aluminum sulfate and soda-ash soln. Slaked lime used at B and C to complete coagulation of aluminum sulfate. Lime preferable, as soda-ash may impart slightly "flat" taste to water. Chief disadvantage to use of lime is sparing soly. Small excess of lime, over requirements, desirable. Accumulates slowly and de-sludging of saturators need be done only at long intervals. At stations A and B, filters discharge directly into mains, but ratio of max. to min. flow at A is 45 : 1 and at B rarely exceeds 3 : 1. Wide variations at A required installation of reciprocating piston meter which, by means of link motion drives chem. pumps, which operate at speeds proportional to rate of flow. Difficulties arising from incorrect chem. dosage more frequent and have greater effect on qual. of filtrate than those resulting from defects in filter design. At all three stations, air wash used. Some sand lost from all filters, both in wash water and in filtrate. At one station, handholes fitted at bottom of each filter at level of concrete bed. These have proved valuable for easy removal of filtering media. Opt. pH value at which filtration takes place is approx. 6.0. Additional alkali required to prevent plumbosolvency in filtered water. Sufficient alkali, therefore, added to bring pH up to approx. 8.5. All filtered water sterilized by chlorination. Chloramination necessary at C to maint. residual chlorine content throughout open service reservoir. Difficulties of wide variation in rate of flow at A overcome by mixing sodium hypochlorite with sodium carbonate injected after filtration; efficient sterilization thereby achieved. In times of little rainfall, gradual accumulation of soot and dust on concrete slopes of reservoir washed into reservoir by next heavy rainfall deteriorating bact. qual. of water in reservoir. Roofing had to be postponed because of war. Records maintd. at works include: meter readings and consumption records; chem. dosages and chlorination; mech. data; and chem. and bact. results. Certain field tests carried out by operators include pH and free alumina. Necessity for frequent checking and calibration of meters cannot be too strongly emphasized. Semi-annual examn. of elec. and mech. plant has proved good investment. Experience shows that heating of main hall, where 7 mgd. (Imp.) passing hardly worth while. Cheaper to provide attendants with coats and gloves. Insistence on high std. of cleanliness

of great value. *Discussion. Ibid.* **46:** 68 (Feb. '43). S. G. BARRETT: How do authors relate color reduction? Is it by noting reduction of, say, orange or yellow alone, or of both together? Many, if not most, water undertakings use Hazen scale of color values. Have authors considered making proposed new basin into coagulating basin? Plant with coagulating basin will function almost precisely as rapid gravity filters, now beginning to receive general approval in this country after almost exclusive use for many years in U.S. 24-hr. supervision of pressure filters surely not universally applicable. Authors to be envied in being able to create chloramine which will persist for 3 days in open reservoir and can, apparently without complaint, re-treat inlet water to open reservoir with 0.6 ppm. chlorine after initial dose. ALAN BOOTHMAN: Clear water reservoirs necessary feature of slow sand filtration, but, where initial head on filters must be retained, choice in first instance may be pressure filters. Is there any reappearance of color in filtrate where lime used both prior to and after filtration? Lime seems to neutralize only certain of peat and humic acids. Writer obtained better results with soda ash prior to filtration and lime as final corrector. Undoubtedly double coagulation provides answer to heavily discolored water as also for waters contg. large quants. of suspended matter. *Author's Reply:* Color reduction practically complete. Hazen scale used in addn. to Lovibond scale. Sedimentation tank being designed with view to using some form of precoagulation. Site conditions alone precluded used of rapid gravity filters. 24-hr. supervision of filter plants feeding direct into mains depends on local circumstances. Any unattended stoppage of chem. gear may result in quants. of water being inadequately treated. With waters in question found that if pH of 6.0 exceeded, color not completely removed and if pH becomes excessive, color may even be dissolved from filters resulting in filtered water worse in color than unfiltered. Ideal treatment for prevention of corrosion of filter shells still being sought. Avg. wash water at Station B is 1%. Disposed of by sewer dept. at £6 per mil.gal. (Imp.).—*H. E. Babbitt.*

Studies on the Filtration of Some Organic Substances in Experimental Slow Sand Filters. J. CHO. Mitt. Med. Akad. Kioto (Jap.) **28:** 991 ('40); Zbl. Ges. Hyg. (Ger.) **47:** 76 ('40). Action of slime forming in surface layer of slow sand filters generally received most attention and action of deeper layers of sand neglected. Tests show org. substances filtered out even in lower layers of sand. Sugar and carbohydrates retained to relatively great extent at depths between 60 and 100 cm. Nitrogenous substances also retained in lower layers of sand. Of substances tried, urea least well retained. Oil-water emulsion chiefly filtered out in upper layers.—*W.P.R.*

Filter Wash Water Troughs and Manifolds. Arc-Welded Construction. ANON. Wtr. & Wtr. Eng. (Br.) **45:** 140 (Oct. '42). Use of welded steel tanks used only once for filter box. Great saving in material and labor costs effected by use of welded steel pipe. Saving in space resulted in use of smaller bldg. Manifolds designed of electrically welded steel. Manifolds consisted of 12-gage plate bent to shape, with ends and bottom of sides flanged to fasten to wood tanks. 32 1" pieces of 2½" std. thread steel pipe welded to sides of manifold. C-i. laterals calked into these sockets with "Hydrotite." Welded manifold cost £8 10s., while cost of c-i. would be £12 10s. Writer favors deep round-bottom wash water trough of variable section, fabricated of steel plate. Deep round-bottom trough parts water smoothly and without deflection at such depth that water reaches streamline flow before reaching surface. Thus, transport of sediment unimpaired. Concrete troughs objectionable because of undesirable shape, rough workmanship and thickness causing needless obstruction in flow area. Arc-welded steel filter plants could be built for about £8750 per mil.gal. (Imp.). Most efficient hydr. properties thereby obtained.—*H. E. Babbitt.*

Chemical Removal of Salts From Water With Activated Carbon. A. A. KOTT. Teplo-Silovoe Khoz. (U.S.S.R.) *No. 8:* 19 ('39); Khim. Referat. Zhur. (U.S.S.R.) *No. 2:* 97. ('40). Removal of salts by combination of H permutit and activated C produces water similar to turbine condensates and evaporator distillates. Water must be filtered twice (through H permutit and activated C) if it is high in Na salts. Commercial activated C can be used for adsorbing anions of mineral acids and salts. C can be regenerated with NaOH, Na_2CO_3 and $NaHCO_3$ solns. Regeneration of C with $NaHCO_3$ reduces amt. of wash water needed and is more economical than other methods.—*C.A.*

TASTE AND ODOR CONTROL

Taste and Control in Public Water Supplies. G. A. H. BURN. Eng. Cont. Rec. **55:** 15: 42 (Apr. 15, '42). Excellent review and discussion of methods for preventing and removing taste and odor. Best method for any particular situation can be detd. only by expt. Preventive measures include reduction of org. matter by draining swamp areas discharging into reservoirs, elimn. of small ponds and shallow areas which encourage growth of microorganisms, controlling algae by $CuSO_4$ addn., preventing decompn. of sludge in settling basins and slime in filters by pre-chlorination, with or without NH_3 addn., or addn. of activated C, and careful control of residual Cl. Methods of removal include aeration, superchlorination, break-point chlorination, activated C filtration and addn. of powd. activated C. De-chlorination may be effected with SO_2, $Na_2S_2O_3$, $NaHSO_3$, catarsit (neutral $CaSO_3$) or filtration through granular activated C or scrap Mg.—*R. E. Thompson.*

Ozone as a Water Purifier in America. ANON. The Engineer (Br.) **173:** 541 (June 26, '42). For long while America trailed behind Europe because it lacked efficient app. of suitable capac. for ozonation. Cost of elec. current did not encourage commercial adoption of ozone process for any considerable vol. of water treatment. Interesting example of successful use of ozone at Denver, Pa., pop. 2100. Plant had rated capac. of 5 lb. ozone daily, and is made up of: air-condg. app., ozonator and ozonizer. In ozonator, dry compressed air passed through silent blue corona discharge between electrodes. In ozonizer, ozonized air contg. about 0.5% ozone introduced into falling water. At Whiting, Ind., because of effectiveness of performance of pilot plant, city installed, in '39, ozone-generating equip. capable of producing 50 lb. of ozone daily. In Europe, prevailing practice is first to filter water, as at Denver, Pa., then to employ ozone; but at Whiting, because of high oxidizing characteristics of ozone, it was added to raw water on theory that much of odor and taste could be "cold-burned," thus increasing effectiveness of filters. Introduction of ozone gave saving in alum, chlorine, and ammonia of $2.56 per day for each mil.gal. water treated. Philadelphia now operating test plant at Lower Roxborough filter plant, costing $25,000, with capac. of 1 mgd.—*H.E. Babbitt.*

Super-Chlorination Experiments With Buenos Aires City Water. DANIEL J. BENGOLEA & RAUL FERRAMOLA. Bol. Obras Sanit. Nacion (Arg.) **10:** 20 (July '42). Operating results at Palermo Water Treatment Plant have verified previous lab. findings as to effectiveness of super-chlorination for removal of odors from La Plata R. water. Ordinarily, break-point can be obtained with 1 ppm. Cl dose. Because of low content of nitrogenous substances in river water, characteristic break-point not always noticeable in chlorine demand curves. Super-chlorination of water leaving settling basins has resulted in 40% reduction in odor, elimn. of anaerobic sporulated organisms from distr. system water and discontinuation of periodic filter disinfection formerly necessary during summer months to prevent excessive development of bacterial growths.—*J. M. Sanchis.*

Activated Carbon as a Byproduct. ANON. Food Indus. **14:** 111 (July '42). (Digest from "Activated Carbon From Certain Agricultural Wastes" by T. R. MCELHINNEY, B. M. BECKER AND P. B. JACOBS. Iowa State College Jour. of Science **16:** 227 ('42).) Activated carbon (C) can be produced from oat and rice hulls, pecan shells, corncobs and other waste materials. Such C's compare favorably with commercial active C's in power to remove objectionable tastes and odors, as indicated by tests with potable waters. Pecan shell C especially active; oat hulls and corncob C's also relatively high. In deodorization tests, pecan shell C ranked above 2 commercial C's. Active C dose slightly > 1 gpg. in water strongly scented with aldol. With pecan shells worth $2.25 per ton delivered, and distn. cost covered by value of volatile products, C therefrom could be produced, activated and marketed for approx. $40 per ton, primary charcoal yield being 27% and activation loss 50%.—*Ralph E. Noble.*

Activated Carbon From Hydrocarbons and Chlorine. G. W. STRATTON & D. E. WINKLER. Ind. Eng. Chem. **34:** 603 (May '42). Activated C produced by burning hydrocarbons and chlorine, and activating by heating at 1000°C. for 90 min. Detn. of iodine, phenol, color and gas adsorption showed new product to be superior in many respects to the various commercial varieties currently being mfrd.—*Selma Gottlieb.*

Color Removing Clays and Their Activation. YVONNE E. STOURDZÉ. Inst. Nacional de Tecnologia (Brazil) Bul. No. 70 ('41). Describes work done at I.N.T. labs. for purpose of evaluating effectiveness of Brazilian clays for decolorizing vegetable oils and to det. possibility of increasing their eff. by activation. Theory of color removal by adsorption and effect which phys. and chem. factors have upon eff. of decolorization processes discussed. Decolorization of oils may be obtained by filtration through layer of active material or by contact process. Contact process ordinarily used because of its dependability and ease of control. Type of clay used, deg. of fineness, amt. added, manner of adding it, speed of agitation and time of contact influence results by contact process. Since decolorizing power of clays depends on their phys. and chem. characteristics as well as on those of oil treated and of pigment to be removed, necessary to det. decolorizing effectiveness by actual test. Decolorizing power of natural clays best tested with cottonseed oil. For comparison of activated clays, linseed oil found better adapted. Activated clays have greater color removal capac. than natural clays. Expts. made to det. possibility of activation of clays by acid treatment have shown that activation better accomplished with strong acids. Optimum acid concn. varies widely with type of material being activated. Optimum can only be detd. by comparing decolorizing power of materials prepd. by treatment with different acid concns. Hydrochloric acid best for activation, but sulfuric acid usually employed because of low cost. In some cases of sulfuric acid activation, has been possible to obtain aluminum sulfate as by-product. Deposits of decolorizing clays so far discovered in Brazil not large, most important being those in São Paulo and in Paraíba do Norte. Because of importance of these clays in development of vegetable oil industry, systematic search being made to find new deposits. Of 5 different types of new clays examd., only 1 appears to have econ. importance. Although true that imported clays (Fuller's earths) superior to those found in Brazil, local products offer advantage of economy and often preferable as admixtures to activated carbon in refining of some vegetable oil products. Procedures for detn. of phys. and chem. properties of natural and activated clays outlined.—*J. M. Sanchis.*

ALGAE CONTROL

How to Handle the Algae Problem. A. E. BERRY. Can. Engr.—Wtr. & Sew. **80:** 9: 17 (Sept. '42). In addn. to causing taste and odor and reducing filter runs, algae cause nuisance when masses decompose in shallow bays and on beaches. Methods of control include chlorination, copper sulfate treatment, exclusion of sunlight and "blacking out" with activated C. Arsenic should not be used in domestic supplies, but may be applied in certain other circumstances. Copper sulfate dosage usually 4–8 lb. per mil.gal. No control measure cure-all and none can be regarded as exceptionally effective. Best to prevent growth if feasible. Fortunately, interference with filter runs usually occurs for only 2–3 wk. in any yr. Accumulation of heavy masses of algae and their decompn. in shallow areas along shore frequent source of nuisance. More prevalent in Ont. in '42. than for some time past. Odor from material highly offensive and occurs at times when use of beaches at max. Appearance of decomposed material not unlike that of sewage sludge. As result, generally associated in mind of layman with inadequate sewage disposal. In Ont. 2 kinds of algae connected with these nuisance conditions—*Cladophora* and *Anabaena*—former being much more prevalent. *Cladophora* has tendency to grow, attached to stones or rocks and reaching to surface, in water up to 4–5′ deep. When alive, growths quite green and free from odor, but become detached by wind and wave action and accumulate and decompose in quiet shallow areas. Growths frequently occur near outlet of creeks or where there is sewage or other org. matter present, although this does not appear essential. During decompn., bright green color turns to gray and finally to black. When broken, texture of decomposed mass not unlike that of sewage sludge. Nuisance occurs in cycles, i.e., heavy growth for few yr. followed by entire freedom for some yr. Most effective control measure removal of growths as they are washed ashore. Fresh growth dries out quickly and does not give rise to odors. Application of chems. would probably not be effective owing to dispersion. Responsibility for control measures is problem. Some reason to believe that removal should be undertaken by property owner and that local municipality should

exercise sufficient supervision to ensure that this takes place. Bed of Navigable Waters Act in Ont. amended in '40 to provide that, where land stated to be bounded by navigable body of water, boundary will be deemed to be high water mark. This point defined as level which has been held long enough to leave watermark along bank, and may be fixed, if necessary, by Minister of Lands and Forests. In general, algae not poisonous. Some people may be allergic to certain growths when in contact with skin, but this not common. Instances of poisoning of cattle recorded. At Fraser Lake, Ont., some yr. ago, about 20 cattle and some other animals died after drinking water in which heavy growth of *Anabaena* undergoing decompn. In this instance, entire lake had pronounced pea-green color. "Pea-soup" appearance and "pig-pen" odor characteristic of heavy growths of *Anabaena*.—*R. E. Thompson.*

Russian Experiences in Controlling the Development of Plants in Water. V. A. LENSKI, P. A. DORFMAN & B. M. JASNOV. Vodos. Sanit. Tekh. (U.S.S.R.) **15:** 2/3: 16; 12: 35 ('40); **16:** 1: 15 ('41); Gesundh. Ing. (Ger.) **64:** 533 ('41). Investigations on control of development of plants in water, by Russian Federal Institute for Water Supply, Sew., Water Works & Water Eng. discussed. Methods of reducing development of water plants in reservoirs, etc., include frequent cleaning of bottom, removal of all plants and roots from land before flooding, drainage of surrounding land to avoid development of plants in shallow pools, cleaning of banks and avoidance of agric. use of surrounding land. Growths of surface phytoplankton can be killed by applications of solns. of chloride of lime, liquid chlorine or copper sulfate. Copper sulfate can be enclosed in sack and suspended in water, but this method gives uneven distr. of copper in water. By spraying powd. copper sulfate over surface of water from boat or from aircraft, even distr. assured and plankton, most of which occurs to depth of 1 to 1.5 m. or, during strong winds, to depth of 2–2.5 m., attacked. By spraying 0.2 or 0.5 g. of copper sulfate per cu.m. of water (estd. from total quant. of water or from vol. of treated surface layer of water resp.) growths of *Microcystis*, *Anabaena*, and *Coelosphaerium* destroyed within 3 days and transparency of water increased from 12–15 cm. to 1.5–2 m. Types of app. used in Russia for spraying copper sulfate described.—*W.P.R.*

A Method of Maintaining the Proper Copper Concentration in the Treatment of Water. O. R. SWEENEY & O. G. FIFE. Proc. Iowa Acad. Sci. **48:** 259 ('41). When excess of satd. soln. of copper sulfate added, with stirring, to sodium silicate, light blue ppt. of copper silicate compd. formed, which settled readily and much less soluble than metallic copper. After contact with metallic copper for 72 hr. or longer, water will contain sufficient soluble copper to kill almost any alga; if lower concns. of copper required under same conditions, copper silicate can be used instead of metallic copper. After contact for 1 hr. with copper silicate, water will contain 0.25 ppm. soluble copper; in this concn. copper toxic to many algae and to trout, carp and catfish, but not toxic to such fish as perch, sunfish and black bass. Lower concns. of copper may be sufficient to prevent growth of many algae though insufficient to kill vigorously growing algae. As most algae do not grow readily in running water, less copper should be necessary in running water than in still water. By allowing water to flow over copper or copper silicate as it passes into storage reservoir, may be possible to control amt. of copper in water; by this method concn. of copper would vary with rate of flow. As water contg. less than 20 ppm. copper considered harmless to human beings, water treated in this way potable.—*C.A.*

Stream Ecology and Available Food. LEONARD I. KATZIN. (*Published in abstract only.*) J. Bact. **44:** 147 (July '42). Study of prin. Ohio R. streams shows certain differences between streams and between portions of same streams, in protozoan, algal plankton and fish pops. Other conditions equal, differences closely related to amts. of food available to plankton as function of amt. of org. material introduced into stream naturally or through man's direct agency. In gen., then, great differences between streams of this basin reflect differences in amt. of org. fertilizer available. Plankton types differentiated as: (1) highly resistant "thrifty" group, able to withstand low temps. and extremes of low food levels; (2) group needing high level of food, usually or often org., and more limited range of temp. tolerance (in gen. group of forms multiplying rapidly under extremely favorable conditions, but of poor resistance); (3) wide group intermediate between these. First group tends toward wide occurrence throughout Ohio basin. Second, less commonly

found, then only during warm summer months. 5 zones characterized in terms of org. content, pH, D.O., protozoan and algal plankton, and fish pop., ranging from grossly pold. regions to those essentially sterile and barren. On this basis, distr. of forms found becomes understandable.—*Ralph E. Noble.*

The Role of the Aquatic Fungi in Hydrobiology. WILLIAM H. WESTON. Univ. of Wis. Symposium Hydrobiol. ('41). p. 129. Most of aquatic fungi are *Phycomycetes*, although few others, such as *Penicillium*, *Sporoclema* and *Loramyces*, also aquatic. These water-dwelling forms abundant and widespread, tolerating wide environmental range. Commonly reproduce by active swimming cells which are small flagellates. One series has single flagellum, usually at posterior end and one series, pair of flagella, commonly lateral. Fungi also produce sporangia and can thus survive drying or unfavorable conditions. Abundance and wide tolerance makes them important in cycle of elements in nature. They are saprophytes and decompose most complex org. matters in direct competition with bacteria. Some few attack lignin, chitin and even siliceous shells of diatoms. Pectins, hemicelluloses and cellulose widely attacked, 12 genera being named as known to possess these powers. As parasites they frequently attack plankton (*Chlamydomonads*, diatoms) and may even terminate "blooms" of plankton in ponds or lakes. Rice seedling sometimes subject to destructive attack. European crayfish industry almost destroyed by aquatic fungus, 1878–1922, though by latter year, intensity greatly diminished. Some remarkable adaptations for actually capturing rotifers, attacking eggs of copepods and other mechanisms described. Fish parasitism by water molds especially noted. Eggs in hatcheries attacked and injured adults readily parasitized—in one instance destroying 50% of brook trout fry in hatchery. Excellent biblio.—*P.H.E.A.*

A Contribution on the Toxicity of Algae. R. E. WHEELER. U.S. Pub. Health Rpts. **57:** 1695 (Nov. 6, '42). Freshly collected *Microcystis aeroginosa* found somewhat toxic for mice and guinea pigs, when given parenterally, but slightly, if at all, toxic when given by mouth. Frozen, or frozen and vacuum-dried, above species much more toxic than freshly collected material for mice and guinea pigs. Toxic substance withstood autoclaving only in neutral soln.; dialyzable, soluble in alc. Survives lab. equiv. of water purif. process—alum coag., chlorination and filtration. Adsorbed upon carbon only when used in comparatively large amts. 3 other blue-green algae nontoxic to mice.—*Ralph E. Noble.*

Photosynthesis of Algae and Other Aquatic Plants. GEO. O. BURR. Univ. of Wis. Symposium Hydrobiol. ('41). p. 163. Submerged plants adapted to low light intensities but not to low CO_2. During day and in shallow water CO_2 tension limiting factor in photosynthesis. Solute concn. and temp. also affect photosynthetic mechanism.—*C.A.*

Studies on Nitrogen Fixation by Blue-Green Algae. G. E. FOGG. J. Exptl. Biol. **19:** 78 ('42). N fixation by *Anabaena cylindrica* does not take place in presence of sufficient amt. of readily available combined N. Cultures of *Anabaena* set up in medium contg. nitrate (KNO_3) and samples of 3, chosen at random, anald. at intervals. N in alga, total N in medium and amt. of nitrate remaining detd. As N in alga increases, corresponding decrease in nitrate N. Extracellular N, other than nitrate, increases as cultures grow older, amtg. to about 14% of total N after 50 days. Total N remains roughly const. until nitrate nearly exhausted. Shows that N fixation does not take place in presence of this form of combined N. N fixation takes place from 40 to 50 days, by which time N in medium has dropped to about 4 ppm. NH_4Cl used as source of N gave comparable results.—*C.A.*

Fixation of Silica by Diatoms. PAUL S. CONGER. Univ. of Wis. Symposium Hydrobiol. ('41). p. 395. Neutral or slightly alk. waters show higher SiO_2 content and frequently have much higher diatom productivity and richer diatomaceous sediments. Silica fixation by diatoms essentially irreversible.—*C.A.*

Fluctuations in the Number of Cells per Colony of the Diatom *Asterionella formosa*. A. C. GARDNER. Proc. Linnean Soc. (Br.) **153:** 160 ('41). *A. formosa* from 3 London reservoirs shows decrease in no. of cells per colony during any period of rapid growth. At start of period of growth, colonies with 8–16 cells common and, later, mean no. of cells per colony may fall to 2.1.—*C.A.*

Biological Studies, Ohio River Pollution Survey. FLOYD J. BRINLEY. Sew. Wks. J. **14:** 151 (Jan. '42). I. *Biological Zones in a Polluted Stream:* Pold. stream divided into 5 zones according to plankton and fish pop: (1) Region of high bact. action, D.O. not over 3 ppm., plankton variable but principally ciliated protozoa (Class II). Carp and buffalo only fish found in region. (2) D.O. between 3 and 5 ppm. Plankton higher than in (1) with increased chlorophyll-bearing flagellates, although still composed largely of Class II organisms. Blue-green algae abundant. (3) D.O. above 5 ppm., often supersatd. in daytime, subject to diurnal variation. Plankton over 1 ppm., usually several, largely intermediate group Chlorophyceae. Fish varied and abundant; suckers, sheepshead, catfish, other market fish. (4) D.O. above 5 ppm., approxg. satn. Plankton between 0.3 and 1 ppm., Class II forms scarce. Game and forage fish predominate. (5) D.O. near satn. Plankton less than 1 ppm., almost entirely *Chrysococcus*, *Cryptomonas* and diatoms (Class I). Fish scarce, compared with (4), mainly game. II. *Plankton Algae as Indicators of the Sanitary Condition of a Stream:* Compared pop. of certain plankton algae species with chem. and bact. indices of deg. of org. poln. in flowing stream. Presence of *Chrysococcus* and *Cryptomonas* in large nos. indicate decompn. of org. matter in stream completed by natural processes, and stream considered clean. Does not imply, however, that water (without treatment) suitable for domestic use. Presence of *Euglena*, *Trachelomonas* and *Phacotus* in large nos. indicates particular vol. of water heavily pold. by org. matter farther upstream and that bact. action reduced org. matter to available plant food, producing rich medium. Plankton pop. gives better picture of past history of certain vol. of water than does san. condition of stream at any definite location.—*Ralph E. Noble.*

Distribution of Stream Plankton in the Ohio River System. FLOYD J. BRINLEY & LEONARD J. KATZIN. Am. Midland Naturalist **27:** 177 (Jan. '42). Report based on 1400 samples collected from most of major watersheds of Ohio basin during '39–'40. Most taken in 250-ml. wide-mouth bottles from stream and preserved with 5 to 8 ml. of formalin. In gen., species found, widely distributed over entire basin. No. of individuals and species increases with warm weather onset, with peak in Aug. and Sept. Exception, Ohio R., where reverse change occurs, largely due to diatoms in spring. Important factor, sharp drop or gradual fall in temp. to 10°C. or less, causing large portion of plankton to vanish. In gen., Cryptophyceae and Chrysophyceae less affected by temp. than other forms. These, therefore, considered typical cold weather plankton. Certain variations introduced by seasonal change in environmental factors termed "pseudo-seasonal"; e.g., upper Ohio R. may show seasonal progressive change of plankton. Chem. data indicate possibly due to progressively increasing acidity from mine drainage and indus. poln. with penetration of this acid condition downstream as flow vol. drops off and summer approaches. Stream receiving largest amt. of org. poln. contains largest no. of species and individuals probably associated with available food. In bact. decompn. of wastes, series of compds. formed which may satisfy nutritional requirements of different organisms in rotation, providing greater variety of ecological niches than in unpold. stream, and allowing appearance of forms not developing under more limited conditions. Differences between northern and southern streams based on higher org. and inorg. food content in northern soils, supporting heavier plankton pops. even in unpold. reaches, and upon differences in seasonal cycles of temp. and weather. Northern streams subjected to winter conditions adverse for plankton growth, conserving food materials until rising temps. in spring and melting snow and ice accompanying initiate spring pulse of plankton often noted. Plankton group consisting of Chrysophyceae, Cryptophyceae and Bacillarieae found under most varied conditions of temp., food concn. and acidity. Resistant or "thrifty" group formed of *Euglena*, *Phacus*, *Lepocinclis*, some Myxophyceae, many Protozoa, depend upon rich food supply largely org. matter and bacteria. Chlorophyceae represents group intermediate in needs and resistance between first two. Complexes of members of second group with large nos. and variety of members of intermediate and thrifty groups clearly indicate nearby org. poln. Thrifty group represented in practically all waters and dominates in clean and impoverished water.—*Ralph E. Noble.*

The Plankton Algae and Protozoa of Two Tennessee Rivers. JAMES B. LACKEY. Am. Midland Naturalist **27:** 191 (Jan. '42). In '39, author surveyed plankton of Cumberland

and Duck R. in Tenn., examg. 18 fresh samples after centrifugation and 48 preserved samples after settling and decantation. Plankton groups described in detail. Stream plankton, unlike that of lake, not likely to indicate clearly condition of water at point of occurrence. If entering substances modify condition greatly, immediate deleterious effect apparent. Otherwise, favors production, increases nos. found downstream according to flow rate and still areas. Difficult to judge nature of stream from plankton content unless biochem.-phys. characteristics well known. Even then, production factors may be missed. Practically nothing known of phosphorus-plankton relationship in streams. In Cumberland, 200 Cryptophyceae and 186 *Chrysococcus rufescens* per ml. found at Nashville, where poln. pronounced. Within few mi. below, marked drop to 4 and 20 per ml. resp. Highest nos., 340 and 400 resp., counted 60 mi. below where river again fairly pure. Thus, 2 flagellated groups behaved similarly in Cumberland and Scioto R. In Duck R., however, they gave little information. Incidence of other forms discussed in possible relation to specific wastes. Effect of canalization considered. *Pandorina* considered poln. indicator when occurring in large nos. River plankton studies should cover considerable time and space if river to be classified. Little doubt that sewage, treated or raw, fertilizes river for distance detd. by amt. of sewage and speed of current. Sufficient fertilizing material would make classification involve amt. of plankton due to sewage rather than geol. and geog. features. In Duck R., probably dealing with "natural" plankton; in Cumberland, one profoundly modified by man-made contributions.—*Ralph E. Noble.*

Plankton Production in Relation to Character of Water in the Open Pacific. HEBERT W. GRAHAM. J. Marine Research **4:** 189 ('41). Total plankton production in open Pacific greater between latitudes 20°N. and 11°S. than between latitudes 20°N. and 34°N. (Sept.–Nov. '29). High plankton and phosphate contents occurred with vertical circulation; not functions of latitude.—*C.A.*

The Effects of Distillery Wastes and Waters on the Microscopic Flora and Fauna of a Small Creek. JAMES B. LACKEY. U.S. Pub. Health Rpts. **57:** 253 (Feb. 20, '42). Introduction of distillery wastes into creek may effect drastic changes in temp., D.O., B.O.D., bact. pop., chem. content (particularly phosphate increase) and tend to reduce plankton content. Some forms tolerant of distillery wastes, at least short distance, provided wastes not too concd. or do not raise temp. too greatly. Group favoring water of high org. content and another favoring oxygen-depleted water partly replaces normal stream plankton. 3 algae (*Chlorobrachis gracillma, Chloroganium euchlora,* and *Chlamydobotrys* spp.) and 2 protozoa (*Oxytricha,* probably *chlorelligera* and a *Spathidium* resembling *viride*) found for some time in relative abundance in these waste waters, although author never encountered them in abundance elsewhere. Whether these 5 characteristic of distillery wastes detd. only by studying other similarly pold. streams. —*Ralph E. Noble.*

Oxygen Production in Green Algae in the Absence of Carbon Dioxide. C. S. FAN & W. W. UMBREIT. (*Published in abstract only.*) J. Bact. **45:** 13 (Jan. '43). Illuminated *chlorella* suspensions capable of producing O_2 in absence of CO_2 when supplied with certain other reducible materials, e.g., acetaldehyde, benzaldehyde, urea nitrate, parabanic acid and ferric salts. Benzaldehyde studied in detail. Under proper conditions, for each 2 benzaldehyde molecules supplied, one O_2 molecule produced. Exptly. CO_2 apparently not an intermediate in this process. Data, therefore, constitute exptl. separation of reactions involved in O_2 production in photosynthesis from those concerned with CO_2 fixation.—*Ralph E. Noble.*

Use of Complete Fertilizers in Cultivation of Micro-organisms. VICTOR L. LOOSANOFF & JAMES B. ENGLE. Science **95:** 488 (May 8, '42). Exptl. work may require large quants. of culture contg. micro-organisms, e.g., recent oyster feeding study required 90 gal. daily for several wk. of culture rich in plankton. Earlier workers found, upon addn. of fertilizers to small bodies of fresh water, phytoplankton increased significantly; followed, in turn, by prolific growth of zooplankton. Authors used complete fertilizers designated by formulas 5–3–5 and 6–3–6 indicating percentages of nitrogen, phosphorus and potash compds. Medium containing 1 g./l. of fertilizer of filtered sea water always gave excellent results; better *Nitzschia* and *Chlorella* growth than with Miquel's soln. Comparatively large quant. of fertilizer should be ground and needed amt. added to water, insuring relative

uniformity of samples. When very large quants. used, as in field expts., grinding unnecessary. Several thousand gal. exceedingly rich cultures of *Chlorella*, *Nitzschia closterium* and *Prorocentrum triangulatum* grown in large outdoor tanks. Chlorophyll-bearing and colorless flagellates grew exceptionally well. *Colpidium*, *Glaucoma* and *Paramecium* (ciliates) produced good cultures. Advantages of complete fertilizers for maintg. stock cultures in lab. and growing mass cultures in field are: (1) One-step method simple, consisting merely of adding 1 g. or less to 1 l. of sea or fresh water. (2) Some constituents dissolve immediately, thus providing nutritive materials for newly started cultures. (3) Other components require time for conversion into utilizable substances. Because of such delayed but continuous supply of nutritive materials, cultures remain viable and active many months, eliminating frequent transfers for stock culture maint. (4) Economical, 1 lb., costing 3 to 5¢, sufficient for nearly 500 l.—*Ralph E. Noble.*

IMPOUNDING RESERVOIRS

Annual Temperature and pH Fluctuation in Five Lakes of Northeastern Ohio. R. W. DEXTER, E. R. SHILLING & N. J. SANNER. Am. Midland Naturalist **28:** 708 (Nov. '42). Surface temp. and pH concn. in Rockwell, Brady, Stafford, Muzzy and Wingfoot Lakes in Portage County, Ohio, measured weekly from Nov. '37 to Nov. '38. Temps. recorded with ordinary mercury thermometer at 4″ depth. pH concn. measured with colorimetric comparators. Samples taken at 5″ to 6″ depth with reversing bottle sampler. All 8 stations close to shoreline; most at end of small docks. All readings taken daily about same time. Weekly surface temp. records of 5 lakes studied in close agreement. Yearly avg., 12.1°C. Avg. for each, within 0.7°, except Rockwell, with 10.8°C. All responded readily and uniformly. Max. temp. 28°C. on Aug. 9. 4 lakes avgd. 7.7 pH; Muzzy Lake, 7.1. Latter more acid, differing from others as much as 1.1. Avg. min. of 6.8 on Dec. 20; return to annual mean by Apr. 22. Avg. max. of 8.3 reached June 8. Lakes fell within 6.5–8.5 range expected. Annual temp. and pH fluctuations correlated in lakes studied. pH value changes seasonal probably due to different rates of photosynthesis in phytoplankton and vascular plants. Photosynthetic activity during warm month reduces acidity. Philip ('27) showed daily changes correlated with weather and light intensity, greatest occurring on sunny days and at sundown.—*Ralph E. Noble.*

Scientific Studies and Chemical Treatment of the Madison Lakes. BERNARD DOMOGALLA. Univ. of Wis. Symposium Hydrobiol. ('41). p. 303. Following conclusions drawn from wealth of scientific data collected on Madison, Wis., chain of lakes during past 18 yr: (1) Spraying method for copper sulfate and other chem. treatments found to be most effective and economical in keeping obnoxious algae or weeds under control. (2) Scientific studies carried on at same time that chem. treatments made show that zooplankton not seriously injured. (3) Chem. lake treatments applied to keep algae under control also kept saprolegnia under control. (4) Chem. spraying of beaches not only kept algae and bacteria under control but also "swimmer's itch" and fungous infections. (5) 18 yr. of scientific studies on lakes show that nitrogen compds., phosphorous, bicarbonate and other factors tend to promote excessive growth of algae and large aquatic plants.—*P.H.E.A.*

Toxic Effects of Sodium Pentachlorophenate and Other Chemicals on Water Hyacinth. A. A. HIRSCH. Botan. Gaz. **103:** 620 ('42). Concn. of 5 ppm. of Santobrite (Na pentachlorophenate) recommended for retarding growth in areas where complete removal of water hyacinth not essential or in zones where other life to be preserved. 80 ppm. recommended for complete elimn. Neither Benoclor 3, a chlorinated hydrocarbon, nor $CuSo_4$ sufficiently toxic.—*C.A.*

The Limnological Role of the Higher Plants. NEIL HOTCHKISS. Univ. of Wis. Symposium Hydrobiol. ('41). p. 152. Many of higher plants represented in lakes, both as emergent rooted plants and as submerged, partly submerged or floating plants, some rooted, some not. Existence and abundance in lake depend on age of lake, depth, fluctuation of level, concn. of salts and nutrient matter, temp. and other factors. Dispersal may be by seeds or propagules carried by animals,

birds or water; spreading by such methods as rhizomes or runners. Succession depends on a variety of environmental factors. Abundant growth tends toward elimn. of habitat by drying and filling lake and occasionally by hastening drying up of lake. They may increase D.O. or lower it. If latter, they frequently promote growth of anaerobic bacteria, as *Clostridium botulinum* which kills ducks and other animals. Various plants also provide food and shelter for representatives of every major animal group. Ducks, muskrats and fish generally benefit greatly from them. Higher aquatic plants would probably prove much more valuable to man if studied from the ecological standpoint and given treatment as are land crops.—*P.H.E.A.*

The Control of Water Chestnut Growths. MAXIM LIEBER. W.W. & Sew. **89:** 3: 95 (Mar. '42). Water chestnut, *Trapa Natans*, appears on water surface as numerous rosettes of leaves, buoyed up by bulbs at base of each leaf. Nut is used as food in Orient but in this country unharvested falls to bottom after maturity, producing new plant following season. On Potomac River near Fort Belvoir, Va., growth so thick sewage polluted water became stagnant, mosquito breeding areas formed and game fishing affected. Chem. treatment, machine and hand cutting tried. Hockney cutter found most economical. Cut plants must be floated ashore and composted. Secondary growths must be eliminated second or third season for complete eradication. Chem. treatment unsuccessful because plants decomposing in water deplete dissolved oxygen.—*F. J. Maier.*

The Role of Oxidizing and Reducing Ions in the Development of Dichotomous Stratification in the pH in Lake Takasuka. KEN SUGAWARA. J. Chem. Soc. (Jap.) **62:** 342 ('41). pH of water in Lake Takasuka, Saitama Prefecture, decreased from surface down to certain depth and then increased down to bottom. For example: pH was 7.0 at 2 m. depth, reached min. of 6.1 at 4 m. depth and increased to 6.9 at 5.75 m. This dichotomous stratification of pH detd. by 2 factors, excess of base and total CO_2 within layer contg. free O_2. In bottom layer where no or little free CO_2 is present, third factor, ferric ions, along with above 2 factors influenced pH. Similar stratification was found also in other lakes of greater or lesser depth.—*C.A.*

Field Studies on the Oxygen Requirements of Certain Freshwater Fishes. WALTER G. MOORE. Ecology **23:** 319 ('42). From field studies made in Minn. lakes on delimitation of summer O thresholds, approx. lethal O concns. for 8 species of fish obtained. O tensions less than 3.5 ppm. at 15–26° fatal within 24 hr. to most species tested, while O concns. of 5 ppm. and over nonlethal to all species tested. Similar data gathered on winter thresholds for 12 species showed that O tensions less than 2.0 ppm. at 0–4° fatal within 48 hr. to most species tested, while tensions of 1.0 ppm. or less fatal to all species, except occasional specimens of *Ameiurus melas* (Raf.). O concns. of 3.0 ppm. and over probably nonlethal to all species tested. Small fishes less tolerant of low O tensions than larger fishes of same species, at both winter and summer temps. Because of delayed lethal effects of low O tensions, importance of duration of exposure in detg. O thresholds emphasized, 24-hr. exposure being suggested at summer temps. and 48-hr. at winter temps. 29 refs.—*C.A.*

The Penetration and Scattering of Solar and Sky Radiation in Natural Water Bodies of the Pacific Northwest. CLINTON L. UTTERBACK. Univ. of Wis. Symposium Hydrobiol. ('41). p. 45. Decreases in intensity of light at varying depths of lake and sea water measured by means of a submarine photometer. "Extinction Coefficients" (rate of decrease of log of light intensity with depth) obtained for red, green, and blue filtered light. Extinction coefs. at Crater Lake for red, green, and blue light: 0.311, 0.060, and 0.031–.036 per m. resp. Values for red light about equal to those found in the N. Pac. sea waters and those reported for distd. water. Values for green light at Crater Lake approx. twice that of distd. water and half that for N. Pac., while values for blue light 5 times that of distd. water and $\frac{1}{3}$ to $\frac{1}{4}$ that in N. Pac. Variations in intensity of solar light and relation of plankton to light extinction coefs. discussed.—*P.H.E.A.*

Sedimentation in Artificial Lakes. STAFFORD C. HAPP. Univ. of Wis. Symposium Hydrobiol. ('41). p. 35. Present rates of sedimentation, usually measurable within year or so, much higher than formerly existed in natural lakes. Due chiefly to man-made changes which increase erosion. In surveying

lake sediments, sometimes possible to make soundings and compare with previous surveys, but usually necessary data not available, and necessary to measure thickness of deposit by means of spud, consisting of steel rod 1½" in diam. with cup-shaped grooves around it at 0.1' intervals. Differences in sediment characteristics at various levels usually distinguishable. Soil augers used where deposits are above water. Annual avg. depletions of storage on 421 artificial lakes amtd. to 0.95% for lakes in southeastern Piedmont area, 1.45% in central lowlands areas and 1.05% in west Gulf Coast Plain. In Los Angeles area, 19 lakes avgd. 9.19% per yr., but this regarded as too high for long-time avg. About 200 cu.ft. of sediment per acre of drainage area per yr. should be max. except under unusual conditions. Within scope of survey, rate of sediment accumulation tends to increase as capac. per unit of drainage area increases up to 300 acre-ft. per sq.mi. of drainage area, but data meager for lakes of higher capac.-drainage area ratio. This probably reflects sedimentation in valley flood plain above lakes and appreciable loss of sediment over outlets for low capac.-drainage area ratios. Delta deposits frequent feature of reservoirs and, beyond this, rather uniform deposit of finer silt, with definite tendency for depression in lake bottom to fill more rapidly, probably due to greater depth of water and greater density of silt-laden waters. Densities of 318 samples of sediments varied from 20.1 to 101.7 lb. per cu.ft., avgg. 54 lb. For 210 samples of "bottomset" beds, always submerged, avgg. 44 lb. per cu.ft. 3 general conclusions reached: (1) Artificial lakes in agric. regions being filled much more rapidly than older, natural lakes, and in lakes draining only forested areas. (2) Sedimentation affects entire lake area and may be more extensive than indicated by visible conditions. (3) Sediment remains soft and uncompacted for at least a no. of years.—*P.H.E.A.*

Silt Problems. W. E. CORFITZEN. Civ. Eng. **12:** 616 (Nov. '42). Subject of silt so widely discussed many wrongly believe nation faces insoluble problem. In arid and semi-arid regions of U.S., material transported largely inorg., thus does not help to nourish fields on which it rests. In designing large dams, necessity of making provision for reservoir silting now recognized. With upstream development and erosion control, life of Lake Mead will probably exceed 500 yr. Air, as well as water, creates silt problem. Strong winds carry away rich soils from farm land and rich lands frequently covered with deposits of inferior soil transported by wind. Accelerated erosion started by man's interference with one or more of natural forces without providing compensating changes in certain other forces to maint. equilibrium. Desilting basin at Laguna Dam example of local method of reducing amt. of silt carried into irrigation system. Satisfactory means of keeping large channels open to construct series of walls extending from each shore at right angles to current. While only fed. govt. can guide and control long-range program, must be stressed that individual action can hinder and wreck program.—*H. E. Babbitt.*

Keeping Debris out of Reservoirs by Soil Erosion Control. ANON. Eng. News-Rec. **128:** 980 (June 18, '42). In '38, East Bay Munic. Util. Dist. introduced reservoir silting studies with view to preventing further erosion damage to watersheds and flow of eroded material into reservoirs, decreasing their capac. Extensive surveys conducted and protective work undertaken, including specially designed non-clogging inlets and protective aprons to prevent erosion at discharge end of culverts under roads, stream bank protection, tree planting, interceptor ditches and flumes around road cuts and areas subject to slides, and constr. of check dams of different types to reduce stream gradient of creeks and gullies. Where height not great, check dams were of rubble masonry; elsewhere, earth fills known as "Missouri type" dams built, in which spillway consists of metal pipe culvert whose upstream end terminates in riser or vertical section that functions as circular spillway. If and when sediment collects in storage basin up to level of spillway lip, addnl. lengths of pipe added. Spillway crest provided with trash rack having vanes to prevent formation of vortex and to keep out debris. Excellent results have attended constr. of these protective works and great improvement made in erosion conditions. Experience with some 45 check dams indicates that grade which silt deposits finally take after ponds eventually fill with detritus varies inversely with size of drainage area. Max. size of material carried by creek naturally affects grade, as coarser material takes steeper slope. On smaller

drainage areas (100–600 acres) silt grade found to be 1.3–2.3%; on larger areas (1000–8000 acres) 0.25–1%.—*R.E. Thompson.*

A Comparison of Some Large Alpine Lakes in Western Canada. DONALD S. RAWSON. Ecology **23:** 143 ('42). Phys., chem. and geol. conditions, lake morphology and quantity of plankton and bottom fauna compared for lakes Bow, Waterton, Minnewanka and Maligne in Rocky Mountains and for lakes Paul and Okanagan in B.C. All lakes have typical oligotrophic features. Total solids and alky. in ppm., mean summer lake temps. and mean surface (0–10 m.) summer lake temps. are 217, 148, 9.4° and 17.7° (Paul); 85, 65, 8.3° and 9.1° (Bow); 82, 72, 8.2° and 12.3° (Waterton); 198, 125, 10.8° and 15.3° (Minnewanka); 104, 64, 6.2° and 10.8° (Maligne); 174, 103, 8.6° and 18.3° (Okanagan), resp.—*C.A.*

Improved Wire Suspension Plan Keeps Sea Gulls Off Reservoir. ANON. Eng. News-Rec. **128:** 500 (Mar. 26, '42). Wire-stringing method on 700 × 1500′ reservoir of East Bay Munic. Utility Dist. at Oakland, Calif., described. Transverse wires placed first, thus providing intermediate supports that greatly reduce stress in longer runs. No. 6 galvanized wire used for transverse runs and No. 11 for longitudinal runs. Wire strung from 2.5″ pipe supports, 6–16′ high, just above high-water line, each support being tied back with 2 pairs of guy wires to oppose pull of catenary. Spacing is 30′ in both directions and turnbuckle is used at one end of each span to adjust sag uniformly. Nearness to coast and frequency of salt fog makes desirable to coat wires with heavy grease to prevent corrosion. Grease applied about once each yr. with aid of scow equipped with trestle.—*R. E. Thompson.*

WPB Order CMP–5 Amended

MANUFACTURERS of water works equipment should note that Order CMP–5, dealing with maintenance, repair and operating supplies under the Controlled Materials Plan, was amended on May 14. This order is concerned primarily with the maintenance and repair of manufacturing properties. *It does not apply to maintenance or operation of water works properties—covered by Utilities Order U–1.*

In the amended form of Order CMP–5, the preference rating AA–2X heretofore assigned to persons engaged in activities listed in Schedule II of the Regulation becomes AA–2. The AA–2 preference rating has been re-established by an amendment to Priorities Regulation No. 1 issued on May 14. The A–10 preference rating, available to persons engaged in businesses not listed on either Schedules I or II becomes AA–5.

Schedules I and II of the Regulation have been completely revised. Some activities and business formerly listed in Schedule II have been transferred to Schedule I and some formerly in Schedule I now appear in Schedule II. These changes will alter the preference ratings which may be used by the industries involved.

The original order was published in the March 1943 JOURNAL (p. 386). Copies of the amended order should be obtained from the nearest WPB office.

The Storage of Coal

By J. F. Barkley

EDITORIAL NOTE: *The combination of wartime demands on railroad transportation and possible irregularity in the future production of coal make it important that water works men store as much coal in advance of their needs as they possibly can. The reluctance of many coal users to maintain large storage has been based on apprehension of deterioration or danger in storage. The document reprinted below will suggest to the user of coal the various proper methods of storage and the precautions to be taken in the use of each.*

Copies of the original document are available from the Bureau of Mines, U.S. Department of the Interior, Washington, D.C., by requesting Information Circular 7235.

DURING the present war emergency, under the urge of the Federal Government to store coal, the following questions are frequently asked by coal users:

a. Will the coal lose any of its heating value in storage?

b. Will it slack and give a smaller-size coal?

c. Will its burning characteristics change in any way?

d. Will it catch fire from spontaneous combustion?

e. What precautions should be taken when coal is stored?

Reprinted from Bureau of Mines Information Circular 7235. This document is a revision and expansion of Bureau of Mines I.C. 7211, "Pointers on the Storage of Coal," by J. F. Barkley, Chief, Div. of Solid Fuels Utilization for War, Bureau of Mines, U.S. Dept. of the Interior, Washington, D.C.

a. Loss of Heating Value

Studies by the Bureau of Mines show that the loss of heating value of coal in storage has commonly been overestimated. Various types of storage tests were made on New River, Pocahontas, Pittsburgh gas and Sheridan (Wyo.) coals. The following is quoted from Bureau of Mines Bulletin 136, "Deterioration in the Heating Value of Coal During Storage," by H. C. Porter and F. K. Ovitz (p. 8):

"Except for the sub-bituminous Wyoming coal, no loss in heating value was observed in outdoor weathering greater than 1.2 per cent in the first year or 2.1 per cent in two years. The Wyoming coal suffered somewhat more loss, 2 to 3 per cent in the first year, and as much as 5.5 per cent in three years."

These figures refer to the heating value of the coal substance itself, free from moisture and ash. If the heating value of one pound of the coal as piled is to be considered, the value would vary with any changes in moisture content; it is also slightly affected by small changes in the weight of the coal, owing to absorption of oxygen and giving off of gases. The coal may actually gain slightly in weight. The heating value is considerably affected if there is actual firing of the coal in storage. M. K. Drewry [1] reports an average yearly heat loss of 0.1 per cent for five fireproofed piles, stored, on the average, about 14 months, and an average yearly loss of 0.9 per cent for five unfireproofed piles, stored, on the average, 4½ months. By "fireproofing" is meant covering the pile with a material such as asphalt or coal dust to cut down the air flow through the pile. These figures of loss are on the basis of total Btu. lost from the pile as a whole and include some losses from coal fines carried away by the wind and from spontaneous heating in spots. The coal stored was a low-moisture coal of about 35 per cent volatile matter.

b. Slacking in Storage

The extent of slacking of coal in storage depends principally on the rank of the coal. The lower-rank coals, such as lignite, sub-bituminous coals, and high-volatile, high-inherent-moisture bituminous coals, slack from weathering much more readily than the higher-rank coals. The slacking, under good storage conditions, ordinarily extends only a short distance into the coal from any exposed surface. Very little, if any, difficulty from slacking should be experienced with the higher-ranking eastern coals. The Bureau of Mines has developed a laboratory test to indicate the tendency of a coal to slack.[2] Studies of these tests showed a wide variation in this tendency, as the "slacking indexes" ranged from about zero for some bituminous coals to nearly 100 for a Texas lignite. For coals having a natural bed moisture up to about 7 per cent, the slacking was small; above this value, the slacking was more erratic and, in general, increased appreciably with the bed moisture content.

c. Changes in Characteristics

Changes in burning characteristics may occur in some coals in storage. Such changes are important primarily for slack-size coals. For example, the caking tendencies of the coal may decrease appreciably. Whether or not the decrease in caking or coking tendencies affects the efficiency of the fuel-burning equipment depends on its type. For example, such a coal would not burn nearly as satisfactorily on a hand-fired down-draft furnace; after being stored for many months it would not stay on the upper grates as well. Storage might improve the coal for use on domestic underfeed stokers or chain-grate stokers; for spreader stokers it would make little difference; for large underfeed stokers the efficiency might be affected. Sometimes coal, particularly low-volatile slack, acts "dead" after long storage, as described by a fireman; that is, it does not seem

[1] Drewry, M. K. Storing Coal Safely. Power Plant Eng. (July 1942) pp. 65–68.

[2] Fieldner, A. C., Selvig, W. A. & Frederic, W. H. Accelerated Laboratory Test for Determination of Slacking Characteristics of Coal. Bureau of Mines Rpt. of Investigations 3055 (1930) 24 pp.

to ignite so readily at the lower temperatures. This tendency is noticeable chiefly in hand-firing, where furnace temperatures are not particularly high. Storage often greatly affects the coke-making properties of a coal.[3] Such effects are reported to appear within a week for some coals; other coals may not be affected appreciably for several years. There may also be slight changes in the mineral matter of the coal, which oxidizes to some extent. Such changes need not ordinarily be given much consideration.

d. Spontaneous Combustion

Whether or not, under given storage conditions, a given coal will heat from spontaneous combustion to any undesirable extent depends on many factors. These factors include: (1) the tendency of that particular coal to take up oxygen, a tendency that decreases as the oxygen is absorbed; (2) the temperature at which the coal is piled; (3) the fineness of any pyrite present; (4) the original size of the coal in the pile; (5) the tendency of the coal to slack; (6) the moisture conditions; (7) the amount of air available to the coal permitted by the conditions of ventilation throughout the storage pile; (8) the presence of foreign substances, such as wood, straw and refuse; (9) the possibilities of dissipating any heat developed; and (10) any added heat from external sources. Owing to the complexity of these factors, exactly when and how much the coal will heat cannot always be judged for every storage condition. It is not difficult to store coal satisfactorily, provided these factors are evaluated correctly and provided the means are at hand for carrying out the proper methods needed for each case.

1. Spontaneous heating is caused by the uniting of the coal with oxygen; it is the same as the burning process in the furnace, except that it proceeds at a much lower rate. The following is quoted from Bureau of Mines Technical Paper 409[4] (p. 64):

"Oxidation of the coal substance itself is the main cause of spontaneous combustion; some of the organic constituents may contribute more to the heating than others, but it has not been shown that any one constituent exerts a preponderant influence to the exclusion of the rest.

"The process of spontaneous heating is operative at room temperatures as soon as freshly broken coal is exposed to the air. It begins with the physical absorption of oxygen and is continued by the formation of a solid chemical compound of coal and oxygen, which is gradually decomposed as the temperature rises. The coal increases in weight by the amount of oxygen retained. There follows the breaking up of the solid compound of coal and oxygen and the formation of the final oxidation products—carbon dioxide, carbon monoxide and water. This process generates heat."

Coals vary a great deal in their natural or characteristic tendency to take up oxygen. In general, it is relatively low for high-rank coals. It is extremely low for anthracite. It is higher for coals of high bed-moisture content, high oxygen content and high volatile content, all of which characterize the low-rank coals. Schmidt reports[3] that

[3] SCHMIDT, L. D. Effects of Storage and Oxidation of Coal Upon Coking Properties. Iron & Steel Engr. (March 1941).

[4] DAVIS, J. D. & REYNOLDS, D. A. Spontaneous Heating of Coal. Bureau of Mines Tech. Paper 409 (1928) 74 pp.

a High Splint Kentucky coal under identical conditions consumed oxygen three times as fast as a Pocahontas No. 3 West Virginia coal.

2. Technical Paper 409[4] (p. 64) may again be cited:

"With the Appalachian coals, oxidation begins to be appreciable at about 85°F. and increases in intensity as the temperature rises. With lower-rank coals the beginning temperature is lower. No coal has as an inherent property a critical temperature at which there is a sharp transition from relatively slow to rapid heating."

The reaction between coal and oxygen is considered to double for about each 15°F. If the temperature of the coal is 60°F. and it is raised to 90°F., the rate at which the oxygen unites with the coal increases four times.

3. According to Technical Paper 409[4] (p. 65):

"Pyrite when finely divided can increase the tendency of a coal to heat spontaneously. Although it has been shown that coals containing virtually no pyrite have fired spontaneously, it has also been quite definitely shown that fine pyrite, when present in the coal, does increase the rate of oxidation."

Pyrite is a compound of iron and sulfur. In general, the sulfur content of coal is largely in the pyrite compound. Pyrite unites with oxygen and water to form sulfuric acid and iron sulfate, giving off considerable heat in the process. Coal users who store coal under the various conditions found in industry are, in general, cautious about the storing high-sulfur coals. Rains or water-flooding of coal may increase the rate of oxidation of the pyrite by supplying needed water or by washing off any products of oxidation formed on it. Pyrite is also accused of disintegrating the coal by its oxidation to bulkier products.

4. An important factor in the heating process is the total surface area of the coal exposed to the air; the greater the surface the more chance of union with oxygen. Table 1 shows the variation of surface area with size.

TABLE 1

Variation of Surface Area of a Ton of Coal With Coal Size

(Coal Considered to Be in the Form of Cubes or Spheres of the Size Designated)

Size	Area per Ton	Size	Area per Ton
	sq.ft.	*mesh*	*sq.ft.*
2.83-ft. cube	48	4	8,727
6-in. lump	272	8	17,416
3-in. nut	544	16	34,796
1½-in.	1,088	30	70,341
¾-in.	2,176	50	139,479
⅜-in.	4,352	100	276,595

For one ton of coal in the form of a solid cube, there is about 48 sq.ft. of surface; as the cube is broken down to smaller sizes, e.g. to slack coal, there may be 20,000 or 30,000 sq.ft. Experience indicates that good-size egg or lump bituminous coal ordinarily gives no trouble from spontaneous heating when stored, mainly because there is not enough surface area.

5. Coals that slack in storage provide more surface area for oxidation.

6. Many persons have found that coal stored wet gives more trouble than coal stored dry. Attempting to cool a coal pile with water frequently creates further hot spots. Changes in wetness affect the ventilation of the pile and also the heating activity of the pyrite. Schmidt of the Bureau of Mines has suggested, in a report un-

published to date, that the movement of water vapor through a coal pile, with any resulting condensation on the coal, could aggravate heating conditions. He calculates that condensation of the small amount of water required to increase the moisture content e.g., from 3 per cent of the weight of the coal to 4 per cent, is sufficient to raise the temperature of the coal over 30°F.

7. Air moving through a pile of coal supplies oxygen for burning and also carries away heat. It may cause increased heating or increased cooling, depending upon the amount. When coal is piled by letting it drop, the larger lumps fall to the outside. Such a pile creates an ideal condition for spontaneous heating. If one spot heats, it will gradually heat the whole pile. There is always the chance that some spot will receive exactly the right ventilation, so that the correct amount of oxygen is brought in and yet not enough heat is carried away. There is much air movement on the outside edges, yet in the center the air can hardly penetrate. There is no ventilation at some spots and much as others. Naturally, somewhere in the pile will be a spot where there is just the right ventilation to produce a "hot" spot.

8. Foreign substances in the coal pile are always a hazard. Pieces of wood, straw or oily rags not only affect the ventilation but frequently create pilot fires to start burning of the coal.

9. If the heat developed spontaneously is removed as rapidly as it develops, the coal temperature will not rise. In a pile of coal where the heat is not removed, however, the temperature rises and the rate of the oxidation or burning increases rapidly; it is self-aggravating. A pile of coal, therefore, might do anything from actually cooling to very rapidly catching fire, depending on how much heat is removed. The time element is involved. A pile of coal might stand three or four weeks without trouble, as it has not had time to heat, but later it might take fire.

10. All sources of external heat should be avoided to the extent possible.

e. Satisfactory Storage Methods

Satisfactory storage of anthracite does not present much of a problem. Householders need not expect to have spontaneous heating troubles with this coal; no occurrences of spontaneous heating of household-size anthracite have been found. Some difficulties have been experienced in careless storing of fine or buckwheat sizes in large, deep piles. Some causes of the trouble have been found to be foreign substances in the coal, an unusual amount of coal dust and considerable heat from external sources. Under the necessary air-flow and temperature conditions, which rarely happen, anthracite will heat spontaneously.[5] The matter is still under investigation.

To assure absolutely that no undesirable heating will develop in any stored bituminous or sub-bituminous coal, it is necessary to use careful methods of storage that either prevent access of air to the coal entirely or provide for access of enough air throughout the pile to carry away the heat as rapidly as it develops. This latter is practicable only for sized coals. Different kinds of coal act quite differently in storage. It is not practical or economical for every plant to obtain

[5] Scott, G. S. & Jones, G. W. Effect of Particle Size on the Rate of Oxidation of Anthracite. Bureau of Mines Rpt. of Investigations 3546 (1941) 15 pp.

the site and equipment needed to carry out methods that would satisfactorily store any and every coal. The problem for each plant is to select the most practical method that will give sufficiently satisfactory results for the kind of coal that is to be stored. Good judgment must be used, based on some knowledge of the causes of spontaneous heating and also on the results obtained for somewhat similar cases. A study is now being made of storage results throughout the United States under the many conditions of storage found in industry; from this it is hoped that information may be made available that will help in predicting the chances of heating for given storage conditions with given coals. To date, no difficulties with spontaneous heating of bituminous coal in the home have been found.

Methods of storage that may be considered include:

1. *Storing Coal Under Water:* This method is desirable from a practical standpoint only under very special circumstances. Water prevents the access of air and hence all spontaneous heating. It does not harm the coal appreciably except to make it very wet, but this often is quite undesirable. If the very fine sizes are removed before underwater storage, the water will drain from the coal much better when the coal is taken from storage. Usually a cheaper and more satisfactory way of storing can be devised for most coals.

2. *Storing in an Open Pit in the Earth:* This scheme is an offshoot of the water-storage method, arising from the attempt to avoid the use of water. The sides of the pit should be in good condition. Segregation of coal sizes should be avoided in placing the coal in the pit; it would be better to spread and compact the coal with a bulldozer tractor. The coal should not have a level higher than the top of the pit. Air has access to the top and to some little extent around the sides of the pit. Covering the coal with a layer of 10 or 12 in. of very fine coal would help to keep out the air. Coals that slack readily, such as sub-bituminous coals, will slack for some inches at the top. Whether or not undesirable heating will develop depends upon how the usual factors affecting spontaneous heating happen to act. This method certainly cuts down the possibilities of air flow and would afford satisfactory storage for many coals, including some of those more difficult to store. If much heating develops, the pit could be flooded with water. It is usually difficult to recover all of the coal in this method of storage.

3. *Storing Slack Coal in Layers:* In this method, layers 2 to 3 ft. in thickness are built up on hard or compacted earth or clay. This base must be free from all rubbish or vegetation. It should have reasonable drainage, but no special drainage schemes such as tile or an ash base that tend to permit access of air into the bottom of the pile should be used. If an ash base is used for drainage, it should be covered with a layer of hard clay to reduce air flow. Any segregation of coal sizes, any foreign material such as straw or sticks in the coal and any external sources of heat should be avoided. The layers of coal should be compacted as with a caterpillar tractor; even an ordinary truck run back and forth over the coal will help. A bulldozer blade mounted on a tractor can be used to level the layers. Compacting the coal can increase the amount of coal per cubic foot from, e.g., 15 to 25 per cent. The sides of the pile ordi-

narily should have an incline of about 35° and should be carefully compacted. Any reasonable height, e.g., 15 to 50 ft., is practicable. This general method will store many eastern coals satisfactorily. Further precautions must be taken, however, for coals that fire more readily. A layer of fine coal dust over the pile helps to decrease air flow; a layer of nut-size coal on top of the dust will hold it down.

There are many general modifications to the above layer method that give satisfaction for many slack coals, particularly for the relatively smaller piles. Layering without compacting is used. Where slack coal is merely piled on open ground, letting the larger pieces segregate to the sides as it falls, trouble may well be expected unless the piles are very small. Such piles should not be over about 6 feet high. For higher piles, even for the best-storing coals, fires have started. The hot spots will start in the center and on the sides of the pile; a wind on the side of the pile will greatly increase the heating. If a trestle comes up through the pile, it provides an air channel that can soon develop heating.

There is a general belief that it is not best to store different coals together or to add new coal to old coal. Different slack coals have different size consists; a modified condition of ventilation is usually created at the joining area of two different coals that *might* be just right for heating conditions. This is particularly liable to happen when the coal is merely allowed to fall into storage with the usual size segregation; leveling the coal into layers breaks up this effect. New coal has a higher rate of oxidation activity than the same kind of old coal. On the other hand, the old coal may have had the needed time to get well started on heating. Different coals have different moisture contents that tend to cause a transfer of moisture. The entire question is one of how the fundamental factors happen to act. There have been countless examples of satisfactory storage where different coals have been stored together.

There is also a belief that if trouble is not experienced with a coal pile for about 90 days no difficulties will develop. Quite often this is true. The decreased rate of oxidation activity of the coal with time develops less heat. Many other factors, however, are involved in the temperature rise of coal; instances of undesirable heating have occurred six to eight months after storage in piles that gave no particular difficulties up to that time. Coal stored in the early fall may not show appreciable heating until the hot summer months.

4. *Capping Coal Pile With Airtight Coverings:* Coal covered so that there is no air flow into and out of the pile cannot give heating troubles. Capping can even put out fires down in the pile. Some have merely covered the inclined sides of the pile. This sometimes will suffice, but it is not nearly as effective as covering the entire pile. Coverings that have been used (other than coal dust) include cut-back asphalts,[1] usually of the MC–1 and MC–2 grades, asphalt emulsion and road tar RT–3 grade. These coverings also prevent coal-dust nuisance, windage loss and moisture penetration.

Experiments by the author's division show asphalt emulsions to be a much better type of covering than the others. Asphalt emulsions having 40 per cent water and also 25 per cent water are on the market. There is little choice in these two asphalts for this purpose; however, the 40-per cent

water material is somewhat easier to handle. The emulsion has the limitation that it might not set well at temperatures below, e.g., 25°F., owing to possible freezing of the water when it is applied on the pile. Where it is necessary to cover a pile at temperatures lower than 25°F., one of the other three materials mentioned could be considered. In general, however, it is best not to cap coal piles at these low temperatures unless absolutely necessary. A capping of asphalt emulsion is not so subject to cracking due to any settling or movement of the coal pile as are the other materials. When coal that has been capped with asphalt is reclaimed from storage, some care would have to be taken if the coal was to be used in pulverizers. Too much material of this type in any one place in the coal would gum up the pulverizer. Introduced into the furnace by fuel-burning equipment, the asphalt burns with the coal.

At present, these materials cost 6 to 12 cents a gallon. A gallon will treat about 1 to 2 sq.yd. of surface to a thickness of $\frac{1}{16}$ to $\frac{1}{8}$ in. For larger piles, this would be equivalent to about 0.1 to 0.2 gal. per ton. On the sides of a pile exposed to prevailing winds, a somewhat heavier coating could be used. The total cost for capping, per ton of coal, would vary with the shape of the pile or the relation of the square yards of area of the pile to the tonnage. It might range from a few cents up to ten cents a ton. One 72,000-ton pile at Washington, D.C., was covered with asphalt emulsion at a total cost, for labor and materials, of about $2\frac{1}{2}$ cents a ton.

Special spraying equipment is available for capping purposes. These coverings are also readily applied by the ordinary road-spraying tank wagon used for spraying tar on roads. The material is heated in the tank wagon to about 125° to 150°F. and can be sprayed through the hand nozzle used on the edges of the road. The hose to this hand nozzle would require lengthening for the larger piles. In one instance a 150-ft. hose was used; one man handled the nozzle to hand-spray the pile, retreating over the pile on the unsprayed coal. Another man moved the hose. Cracked capping can be patched in the same general manner. Any point on the pile can be reached by means of ladders to which boards have been nailed crosswise and by planks for walkways. Where equipment is available, the entire tank wagon can be swung over the pile, using the usual rear road spray. It is best, particularly for the larger piles, to spread and compact the coal with a tractor or similar means; this greatly decreases any tendency of the pile to settle and also decreases possible air movement through the pile. Large sheets of paper have been used in storage piles to stop the movement of air.[6]

Other capping materials tried have been portland cement, with coal dust for the aggregate, and even plaster of Paris.

Completely satisfactory information is not available as to the exact effect on heating in storage of coals sprayed with the usual oil or salt sprays. Apparently these do not increase troubles in any way and sometimes may be beneficial.

5. *Storing in Bins, Bunkers and Silos:* For best results with this type of storage, all foreign material, such as sticks and oily rags, should be removed, segregation of sizes and ex-

[6] Blast Furnace & Steel Plant (November 1941) p. 1135.

ternal sources of heat should be avoided and the access of air prevented. Usually the handling equipment for such storage appears designed to segregate sizes rather than prevent it. Many of the difficulties now being experienced in bins, bunkers and silos could be lessened greatly if care were taken as to how the coal was spilled by the chutes. Another chronic trouble in present equipment is its inability to spill all the coal. There are corners or spaces in which old coal will remain until hand-shoveled, often causing heating difficulties as previously mentioned. It is seldom realized what a relatively large amount of air can flow into the coal through small slits, cracks or poorly closing gates. Some air usually flows up through a coal chute having the ordinary cut-off and on up into the bunker, whether or not the chute is full of coal. This applies particularly to high silos. Often air flow can be located with an ordinary candle flame. Most coals piled into a container really *airtight* on sides and bottom will not fire from air that reaches it only at the top. A layer of fine dust over the top is additional protection.

6. *Storing Sized Coals:* Sized coals with the fines removed give much less difficulty from heating. In such piles, the relatively small amount of coal surface develops only a small amount of heat, which can readily be dissipated. In general, the higher-rank coals with the fines screened out may be stored without difficulties from heating. An arbitrary lower size limit of ¼-in. might be chosen. These are instances of storage of washed Illinois 10-per cent moisture coals with a minimum size much less than this giving no trouble from heating. Conditions are changed somewhat if the sized coal slacks in storage, producing much fines.

7. *Storage in the Home:* Spontaneous heating difficulties in the small piles usually stored in home should not be expected with sized bituminous coals; no example of spontaneous heating has been found to date with slack bituminous coals. The ordinary precautions should be taken, however, to avoid foreign materials, sources of excessive heat and appreciable size segregation. Slack-size coal should be leveled about every 18 in. as it goes into the bin. For slack coals a height of 6 ft. is a good limit. The pile may be examined at intervals to note any unusual conditions. For a coal that is considered hard to store, such as a low-rank or a sub-bituminous coal, added precautions should be taken. The bin should be made thoroughly *airtight;* slits or cracks in the bin should be closed and a removable partition should be built over the bin outlet or shoveling door. The coal should be leveled at the top. An airtight cover over the top could be considered for very high-moisture coals.

Temperature Observations

The temperature of a coal pile should be tested periodically with a thermometer or an equivalent scheme. This gives plenty of warning and ample time to avoid anything dangerous; it is only when the pile has been ignored that matters might get somewhat out of hand.

Lengths of ordinary gas pipe of about ¾-in. size, closed at the bottom, reaching nearly to the base of the coal, may be placed about every 25 ft. A thermometer may be dropped down the pipe to explore for temperature. The pipe should not be removed once it has been inserted, as this ordinarily leaves a little chimney in the coal, which facilitates heating. If a temperature of

about 120°F. is reached, the coal should be watched closely for any rapid rise in temperature. Plans should be completed so that the coal can be moved when desired or satisfactorily water-flooded. Sometimes the temperature will rise slowly to as high as about 160°F., then fall; at other times it will continue to active firing conditions.

Generally the coal must be moved when too much heating develops. The heated coal can be spread out to cool; often it is more convenient to use it at once.

Using water to put out a fire may be effective for the moment, but in many instances this only delays the necessity of moving the coal. If the equipment available permits thoroughly flooding the coal with water, the heating can be stopped. Generally, this flooding must be repeated at intervals. Spraying the top of the pile with water from a nozzle usually is ineffective; the water seldom gets down to the hot spot. It would be better to ram the nozzle down into the coal. Sometimes a mass of coke that the water cannot penetrate forms over the hot spot.

Improvement has been found in the use of the "water spear." The spear is made from pipe about 1 to 2 in. in diameter, closed at the bottom in a sharp point. Side outlet holes are drilled into the pipe just above the point. At the other end of the pipe is a hose connection. A cross handle may be used at the top of the spear to aid manipulation. The spear is rammed down into the pile to the hot spot, facilitating water flooding.

Small storage fires have been put out by smothering with carbon dioxide gas. Either dry ice (frozen carbon dioxide) or the tanked liquid carbon dioxide may be used as a source of the gas. This method is based on the fact that if oxygen is prevented from reaching the coal the fire will go out. Use of carbon dioxide must be carefully planned and proper ingenuity used for satisfactory results.[7] The oxygen must be kept from the coal long enough for it to cool appreciably. Heating may redevelop after the carbon dioxide disappears. For some conditions, its use may provide the needed delay in the burning.

[7] GUTLEBEN, DAN. Fighting Coal-Bunker Fires. Power (January 1942) p. 102.